Drosera anglica Huds. (English sundew): A Technical Conservation Assessment

Prepared for the USDA Forest Service,
Rocky Mountain Region,
Species Conservation Project

December 14, 2006

Evan C. Wolf, Edward Gage, and David J. Cooper, Ph.D.
Department of Forest, Rangeland and Watershed Stewardship
Colorado State University,
Fort Collins, CO 80523

Peer Review Administered by
Center for Plant Conservation

Wolf, E.C., E. Gage, and D.J. Cooper. (2006, December 14). *Drosera anglica* Huds. (English sundew): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/droseraanglica.pdf [date of access].

Acknowledgments

Numerous people helped us in the preparation of this assessment by contributing ideas, data, photographs, or other forms of assistance. The Wyoming Natural Diversity Database provided element occurrence data and habitat information essential to the document. We also wish to thank the many USDA Forest Service personnel who provided help or guidance, including Kent Houston, Steve Popovich, John Proctor, Kathy Roche, and Gary Patton. The Rocky Mountain Herbarium provided important information, as did several individuals including Bonnie Heidel, Sabine Mellmann-Brown, and Christopher Cohu. Thanks also to Rachel Ridenour and Emily Drummond for their assistance. We would like to thank David Anderson for making available earlier drafts of his Species Conservation Project assessments, which were helpful in organizing our work. And finally, thanks to Joanna Lemly for information on the newly discovered Colorado occurrence.

Authors' Biographies

Evan Wolf, M.S., is a research associate with Colorado State University, living and working in California where he is involved in a number of mountain wetland research projects. He spent nine years in Colorado, four earning a B.A. in Geology at Colorado College, two as a GIS specialist with the Inland West Water Initiative at the Forest Service Region 2 Headquarters, and three earning an M.S. in Ecology from Colorado State University.

Edward Gage, M.S., is a research associate at Colorado State University. He earned a B.S. in Natural Resource Ecology from the University of Michigan and an M.S. in Ecology from Colorado State University. His research and project experience include wetland and riparian inventory and mapping work, hydrologic, ecological, and functional wetland assessments, studies of native ungulate and riparian vegetation interactions, and studies of anthropogenic impacts to riparian and wetland ecosystems.

David J. Cooper, Ph.D., is a senior research scientist in the Department of Forest, Rangeland and Watershed Stewardship, and an advising faculty member in the Graduate Degree Program in Ecology at Colorado State University, where he has worked for 12 years. He received his bachelors and Ph.D. degrees at the University of Colorado, Boulder, working on arctic and alpine tundra ecology. For the past 20 years his research and teaching have involved wetland and riparian ecosystems in western North America, and he has expertise in floristics, classification, ecosystem restoration, hydrology, geochemistry and geomorphology.

Cover Photo Credit

Drosera anglica (English sundew). Photograph by Juergen Bernt (used with permission).

Summary of Key Components for Conservation of *Drosera anglica*

Status

Drosera anglica (English sundew) has a circumboreal distribution and is widespread and abundant in many regions. Globally it is not threatened with extinction in the near future and is ranked as G5, apparently secure. However, the three occurrences located in USDA Forest Service Region 2 are geographically isolated and near the southern extent of the species' range. In the state of Wyoming, the species is ranked S2, imperiled. In Colorado, *D. anglica* has only recently been discovered, so no state status has been assigned. It will likely be ranked S1, imperiled, due to its regional rarity.

The three verified Region 2 occurrences of *Drosera anglica* are in fens in Wyoming and Colorado. The two Wyoming occurrences are on floating mats along the margins of small lakes while the Colorado occurrence is in a basin fen. Fens are uncommon in the Rocky Mountains and are critical to the persistence of these *D. anglica* occurrences. *Drosera anglica* is exceptionally well adapted to the waterlogged and nutrient poor environment of fens – it derives a significant proportion of its nutrients through carnivory – and cannot compete and survive in any other habitat.

Primary Threats

The most immediate threats to *Drosera anglica* are events that alter the hydrologic functioning of the fens in which it occurs. Water-saturated conditions produced by perennial groundwater discharge are critical for maintaining slow rates of organic matter decomposition and slow nutrient turnover. Activities that disrupt, divert, augment, or redistribute groundwater flow to and through a fen have the potential to alter ecosystem functions and the floristic composition of fens. Site-wide impacts may occur directly in the fen from activities such as ditching or groundwater pumping. Other impacts can occur from activities in adjacent ecosystems, including logging, fires, road building, diverting surface flow, and pumping groundwater.

Within a fen, a variety of microsites occur that influence the distribution of fen plant communities. Activity within the fen can significantly affect the quality and abundance of microsites. For example, trampling by cattle, people, vehicles, and native animals can break apart floating peat mats that provide *Drosera anglica* habitat.

Any change in the nutrient budget of a fen can significantly alter site suitability for *Drosera anglica*. Being adapted to nutrient poor environments, *D. anglica* would likely be out competed if fertilization were to occur via atmospheric deposition of nitrogen, excrement of rangeland grazing animals, or if there were other increases in the nutrient concentration of the water supporting the fen.

Primary Conservation Elements, Management Implications and Considerations

The principle consideration when making conservation decisions for *Drosera anglica* is to ensure that the ground and surface water flow regimes remain unaltered. This necessitates a full understanding of the hydrologic processes in sites supporting *D. anglica* occurrences. Intra- and inter-annual groundwater and surface water data are essential to identify water sources, flow paths, and the range of variability in flow to fens and water levels in fens.

The integrity of the peat body in which *Drosera anglica* roots is the second most important management concern. Direct physical impact from hooves, feet, and tires is the most common source of damage to the interwoven mass of roots, rhizomes, and undecayed organic matter. In the southern Rocky Mountain region, peat takes an extremely long time to accumulate, but if broken apart and exposed to air, it will decompose relatively rapidly. The peat body's structure provides much of the microsite variation critical to fen plants, including *D. anglica*.

Another detrimental impact to peat accumulating ecosystems is the input of mineral sediment. Peat is composed primarily of undecayed plant material, and its physical properties, such as capillarity, bulk density, chemistry, and water holding capacity, are altered when inorganic sediment is added. Any action that leads to significant amounts

of mineral sediment input to a fen will alter the microsite hydrologic and geochemical regimes in the peat body, potentially reducing the habitat suitability for *Drosera anglica*.

TABLE OF CONTENTS

ACKNOWLEDGMENTS 2
AUTHORS' BIOGRAPHIES 2
COVER PHOTO CREDIT 2
SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *DROSERA ANGLICA* 3
Status 3
Primary Threats 3
Primary Conservation Elements, Management Implications and Considerations 3
LIST OF TABLES AND FIGURES 7
INTRODUCTION 8
Goal 8
Scope and Information Sources 8
Treatment of Uncertainty 8
Publication of Assessment on the World Wide Web 9
Peer Review 9
MANAGEMENT STATUS AND NATURAL HISTORY 9
Management and Conservation Status 9
Global rank 9
Federal status 9
USDA Forest Service regional designation 9
State rank 9
Existing Regulatory Mechanisms, Management Plans, and Conservation Practices 10
Biology and Ecology 10
Classification and description 10
Systematics and synonymy 10
History of species 10
Morphological characteristics 11
Distribution and abundance 12
Global abundance 12
USFS Region 2 abundance and population trends 14
Reproductive biology and autecology 16
Reproduction 16
Life history and strategy 16
Pollinators and pollination ecology 17
Dispersal mechanisms 17
Seed viability and germination requirements 17
Cryptic phases 18
Mycorrhizal relationships 18
Hybridization 18
Demography 19
Life history characteristics 20
Ecological influences on survival and reproduction 20
Genetic characteristics and concerns 21
Factors limiting population growth 22
Community and ecosystem ecology 22
General habitat characteristics 22
Substrate characteristics and microhabitats 24
USFS Region 2 habitat characteristics 25
Water and peat chemistry 26
Wetland hydrology 27
Vegetation associations and associated plant species 27
Competitors and relationship to habitat 28
Herbivores and relationship to habitat 28

Parasites and disease....28
Symbiotic and mutualistic interactions....28
CONSERVATION....30
Threats....30
Hydrologic alteration....30
Timber harvest....30
Fire....30
Roads and trails....31
Peat extraction....32
Mineral development....32
Livestock and native ungulate grazing....32
Recreational impacts....33
Over-collection....33
Exotic species....34
Atmospheric deposition of pollutants....34
Climate change....34
Conservation Status of *Drosera anglica* in Region 2....34
Management of *Drosera anglica* in Region 2....36
Implications and potential conservation elements....36
Tools and practices....36
Availability of reliable restoration methods....36
Information Needs and Research Priorities....37
DEFINITIONS....38
REFERENCES....41
APPENDIX....50

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

List of Tables and Figures

Tables:

Table 1. *Drosera anglica* occurrences in USDA Forest Service Region 2. 15

Table 2. Comparison of water pH and calcium (Ca^{2+}) and magnesium (Mg^{2+}) ion concentrations (mg/L) measured in wetlands with *Drosera anglica*..... 27

Table 3. Common vegetation associates for *Drosera anglica* reported from various studies outside USDA Forest Service Region 2. 29

Figures:

Figure 1. Rosette of leaves and flowering scape of a *Drosera anglica* individual in California. 11

Figure 2. Close up photographs of *Drosera anglica*..... 12

Figure 3. Hemispheric distribution of *Drosera anglica*..... 13

Figure 4. Distribution of main peat-forming areas in the continental United States. 13

Figure 5. Distribution of *Drosera anglica* within USDA Forest Service Region 2. 14

Figure 6. Arthropod composition of the prey captured by *Drosera anglica*..... 17

Figure 7. Seed germination in relation to burial depth for *Drosera rotundifolia*. 18

Figure 8. Hibernacula of *Drosera anglica*. 19

Figure 9. Life cycle diagram for *Drosera anglica*. 20

Figure 10. Population growth rate for each of four one-year-periods, quartiles for depth to water table, and peat production ability. 21

Figure 11. Illustration of hillslope fens associated with a bedrock contact or a bedrock fracture. 23

Figure 12. Illustration of upwelling groundwater at the toe of a hillslope supporting a spring mound fen. . 24

Figure 13. Illustration of a closed basin where groundwater feeds a lake that supports a floating mat fen. . 24

Figure 14. Illustration of sloping fen that formed where groundwater flow is concentrated. 24

Figure 15. The local distribution of northern European *Drosera* in a blanket bog. 25

Figure 16. Oblique photograph of the Park County, WY 2 wetland, Shoshone National Forest, WY. 25

Figure 17. Floating mat at the Park County, WY 2 wetland, Shoshone National Forest, WY. 26

Internal Figure 17. Topographic map and aerial photograph of the Park County, WY 2 (Lily Lake) wetland, Shoshone National Forest, WY. 50

Internal Figure 18. Topographic map and aerial photograph of Park County, WY 1 (Little Moose Lake) wetland, Shoshone National Forest, WY. 51

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). *Drosera anglica* Huds. (English sundew) is the focus of an assessment because within Region 2, it is a disjunct species with an extremely limited distribution, and therefore the viability of the population is a concern. Within the USFS, a species 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 may be designated a sensitive species (USDA Forest Service 2005a). The USFS lists *D. anglica* as a sensitive species in Region 2 (USDA Forest Service 2005b). A sensitive species may require special management, so knowledge of its biology and ecology is critical. This assessment addresses the biology, ecology, conservation status, and management of *D. anglica* throughout its range in Region 2. The introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal

The goal of this document is to provide a comprehensive and synthetic review of the biology, ecology, and conservation status of *Drosera anglica* within USFS Region 2. The assessment goals limit the scope of this work to critical summaries of scientific knowledge, discussion of broad implications of that knowledge, and outlines of information needs. Since *D. anglica* occurs only in specific types of wetlands, the report focuses on factors controlling the hydrologic regime and geochemistry of these wetlands since these variables represent key ecological drivers of the structure and function of wetlands. This 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 and Information Sources

Within this assessment, a synthesis of current knowledge addresses a wide variety of topics relevant to the basic biology, ecology, and conservation status of *Drosera anglica*. Considering the broad scope of the assessment, a range of information sources was consulted, including peer-reviewed scientific literature, non-peer-reviewed literature (e.g., theses, dissertations, and agency reports), herbarium records, and Geographic Information System (GIS) data sources such as element occurrence records from state natural heritage programs in the region. Where appropriate, unpublished data, reports, and conversations with known experts have been incorporated.

The emphasis of this assessment is on *Drosera anglica* within Region 2. However, the species has a wide geographic distribution throughout the northern hemisphere, and considerable information is available from outside the region. Though topics discussed in this assessment are largely set in the context of current environmental conditions, information regarding evolutionary and biogeographic aspects of both the species and the wetland types in which it occurs has been included where possible. These broader perspectives are essential for developing realistic assessments of current and future conservation threats.

Treatment of Uncertainty

Ecological systems and the biota inhabiting them are, by nature, exceedingly complex. Multiple variables influence any given ecological attribute. Key variables frequently lack independence and are difficult to isolate and effectively measure, further complicating data collection and analysis. Moreover, ecological patterns and processes are often strongly scale-dependent, with generalizations appropriate at one scale being inappropriate at another scale. When preparing a broad-scale assessment such as this one, it is important to address issues of uncertainty explicitly.

Though widely distributed globally, *Drosera anglica* occurs at only a very few sites within Region 2. Unfortunately, there are scarce quantitative data on many aspects of *D. anglica* available from known Region 2 occurrences, making definitive statements about the ecology or conservation status of the species in the region difficult. However, because of its wide distribution and its interest as one of a limited number of carnivorous plant species, *D. anglica* has been extensively studied elsewhere. These studies have been used to make inferences about the species in Region 2, but because it is easy to misapply research findings outside of their original ecological context, the use of these data has been judicious.

Considering the lack of rigorous, experimental research conducted on *Drosera anglica* within Region 2, this report incorporates extensive knowledge of the particular wetland types where the species occurs. In concert with insights provided by other scientists

and managers and careful extrapolation of work conducted outside the region, this report provides a first approximation of the species' biology, ecology, and conservation status. To help readers evaluate the conclusions made, the strength of evidence for particular ideas is explicitly noted throughout the assessment, and where possible, alternative hypotheses are provided.

Publication of Assessment on the World Wide Web

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

Peer Review

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

MANAGEMENT STATUS AND NATURAL HISTORY

Management and Conservation Status

Global rank

The Global Heritage Status Rank for *Drosera anglica* is G5, globally secure, as a result of its scattered distribution over a very broad range (NatureServe 2006).

Federal status

Drosera anglica is neither listed nor a candidate for listing under the Endangered Species Act and has no national status rank (NatureServe 2006).

USDA Forest Service regional designation

USDA Forest Service Region 2, which encompasses Colorado, and parts of Kansas, Nebraska, South Dakota, and Wyoming, lists *Drosera anglica* as a sensitive species due to its disjunct distribution and restriction to rare habitats that are unusually sensitive to disturbance. *Drosera anglica* is also listed as sensitive by USFS Region 1, which encompasses Montana, northern Idaho, eastern Washington, western North Dakota, and western South Dakota (USDA Forest Service 2004a).

Both the Wyoming and Colorado offices of the Bureau Land Management (BLM) maintain their own lists of sensitive species within their respective states, and neither considers *Drosera anglica* a sensitive species (Bureau of Land Management 2000, Bureau of Land Management 2002).

State rank

Drosera anglica is listed as imperiled (S2) within the state of Wyoming because of its rarity (6 to 20 occurrences, or 1,000 to 3,000 individuals), or because other factors demonstrably make it very vulnerable to extinction throughout its range (NatureServe 2006). Additionally, the Wyoming occurrences are ranked as high contributors to the range-wide persistence to the taxon (Wyoming Natural Diversity Database 2004) because they represent a disjunct range extension. The species has only recently been discovered in Colorado, so no status has been assigned. It will likely be ranked S1, imperiled, due to its regional rarity.

Several states and provinces outside of USFS Region 2 list *Drosera anglica* as a plant with special status. Wisconsin, Maine, and New Brunswick list the plant as critically imperiled (S1) because of extreme rarity (often 5 or fewer occurrences) or because of some factor(s), such as very steep population declines, making it especially vulnerable to extirpation. *Drosera anglica* is imperiled (S2) in Montana and imperiled/vulnerable (S2S3) in California. Minnesota, Michigan, Alberta, Saskatchewan, and Manitoba list the species as vulnerable (S3) due to a restricted range, relatively few occurrences (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation. *Drosera anglica* is vulnerable/apparently secure (S3S4) in Quebec and vulnerable/secure (S3S5)

in Labrador and Newfoundland Island. The plant is apparently secure (S4) in British Columbia where it is uncommon but not rare, with some cause for long-term concern due to declines or other factors. Ontario lists *D. anglica* as secure (S5) because it is common, widespread, and abundant (NatureServe 2006).

Explanations of the Natural Heritage Program ranking system are found in the **Definitions** section of this document.

Existing Regulatory Mechanisms, Management Plans, and Conservation Practices

USFS Region 2 has designated *Drosera anglica* as a sensitive species (USDA Forest Service 2005a). As such, it is protected under the Code of Federal Regulations, and damaging or removing any plants is prohibited (Code of Federal Regulations 2006, Section 261.9). In addition, the USFS is bound by certain directives regarding the management of sensitive species (USDA Forest Service 2005b).

Drosera anglica is an obligate wetland species (i.e., restricted to wetland habitat) (Reed 1996). The wetlands that support occurrences of this species receive some protection under existing federal, state, and local statutes. For instance, Section 404 of the Clean Water Act has historically placed regulatory oversight on a range of activities affecting wetlands with the U.S. Army Corps of Engineers (USACE). Executive order 11990, signed by Jimmy Carter, instructs federal agencies to "minimize the destruction, loss or degradation of wetlands." However, a recent Supreme Court decision (SWANCC vs. USACE) has effectively removed federal regulatory oversight for wetlands that lack connections to surface water bodies, such as streams. Most fens are not connected to navigable waters via surface flow and therefore may be considered isolated under USACE jurisdiction through the Clean Water Act (Bedford and Godwin 2003).

The Forest Service Manual chapter 2520 (USDA Forest Service 2004b) and the USDA Forest Service Technical Guide to Managing Ground Water (USDA Forest Service 2005c) provide agency-wide guidance on the definition, protection, and management of wetlands. Forest Service Handbook series 2509.25 (USDA Forest Service 2006) covers wetland management directives specific to Region 2. Regional guidance on fens is provided by USFS memo 2070/2520-72620, signed by the Director of Renewable Resources, which emphasizes the protection, preservation, and enhancement of fens to all Region 2 forest supervisors (Proctor 2004 personal communication). The U.S. Fish and Wildlife Service addresses the protection of the wetland types specific to *Drosera anglica* habitat as well (U.S. Fish and Wildlife Service 1997, Gessner 1998). If properly executed and enforced, these directives and regulations should help to identify, preserve, and protect *D. anglica* occurrences and habitat.

Biology and Ecology

Classification and description

Systematics and synonymy

Drosera anglica Huds. is a member of the family Droseraceae, which contains two other carnivorous snap-trap genera, *Dionaea* (Venus flytrap) and *Aldrovanda* (waterwheel plant). Droseraceae is classified in the order Caryophyllales, in a clade with three other families containing carnivorous genera, the Nepenthaceae, Drosophyllaceae, Dioncophyllaceae, and one non-carnivorous family, the Ancistrocladaceae. Carnivory evolved in several other plant groups, but snaptrap-type carnivory is only found in the Caryophyllales (Stevens 2001). This indicates convergent evolution of the general trait of carnivory but a common origin of the specific snap-trapping mechanism (Cameron et al. 2002). The order Caryophyllales belongs to the class Magnoliopida (dicotyledons), division Magnoliophyta (flowering plants), super-division Spermatophyta (seed plants), sub-kingdom Tracheobionta (vascular plants), in the kingdom Plantae (plants) (USDA Natural Resources Conservation Service 2004).

Presently, two forms of *Drosera anglica* are recognized. The first, *D.* x *anglica*, is a sterile, diploid hybrid between *D. rotundifolia* (round-leaved sundew) and *D. linearis* (linear-leaved sundew). *Drosera anglica* also occurs as a fertile tetraploid; only the presence of filled seed capsules can be used to distinguish fertile and infertile forms of the plant in the field (Schnell 1999). No varieties are recognized in North America, but several varieties have been described in the European Alps and Scandinavia (Crowder et al. 1990).

History of species

William Hudson originally described *Drosera anglica* in 1778 (Hudson 1778). Twenty-five years earlier, Carl Linnaeus described *D. longifolia*, which is now recognized as a synonym of *D. anglica*. Though the use of *D. longifolia* by Linnaeus in 1753 predates that of *D. anglica*, *D. longifolia* has been inconsistently

applied to what are now regarded as two distinct species, *D. anglica* and *D. intermedia*, and so *D. longifolia* has since been rejected (*nom. ambig. rejic.*) (Schnell 2002). Hudson is considered the authority, and his collection the original, because it was the first to describe the diagnostic features of the taxon: the stipules and seeds (Wynne 1944). The lectotype specimen is housed in the herbarium of the Linnaean Society of London.

Extensive work has since followed on the genetics, biology, ecology and especially the carnivory of the genus *Drosera*. Charles Darwin discussed *Drosera* in his 1875 publication "Insectivorous Plants", and his brother Francis conducted experiments on the nutrition of *Drosera* (Darwin 1878). Most current research on *D. anglica*, from the genetic level up through ecosystem processes such as climate change and aerial nitrogen deposition, has occurred in Europe. Relatively little research has been conducted in the western United States, with a handful of studies noting its presence in California (Erman and Erman 1975), Wyoming (Heidel and Laursen 2003a), Idaho (Moseley et al. 1991, Bursik and Moseley 1992), Montana (Cooper and Jones 2004, Montana Natural Heritage Program 2005) and a disjunct occurrence in Hawaii (Mazrimas 1987).

Morphological characteristics

Drosera anglica is an herbaceous perennial plant with a basal rosette of leaves and a single, vertical, flowering scape (**Figure 1**). The leaves attach spirally in a basal, erect rosette, consisting of long, flat, narrow, petioled, pubescent leaves (a looser rosette than *D. rotundifolia*). The leaves are divided into two parts: a linear petiole 1 to 7 cm in length and a terminal narrowly obovate blade modified into a trapping mechanism up to 2 to 5 mm across and 15 to 40 mm long (**Figure 2**; Crowder et al. 1990). The petioles are green and hairy (sometimes glabrous), and contain large air spaces. On the adaxial surface of the blade are two forms of tentacular red stalked glands, about 200 per lamina, all perpendicular to its surface, which secrete a glutinous, dewdrop-like substance. The longer, sensitive stalks located on the periphery of the leaf blade function to entrap prey, whereas the short to sessile stalked glands secrete digestive fluids (Lloyd 1942).

Prey are lured to the traps by the plant's brilliant reddish coloration, which is a result of a high concentration of the pigment plumbagin in the petioles and glandular hairs (Swales 1975). The leaves of *Drosera anglica* possess a unique mechanism for bending: once entrapment has occurred, the leaf petiole folds over the captured prey and prevents the escape of the insect (Darwin 1875). This is brought about by the hyponasty of a more or less narrow zone of the petiole at the base of the blade (Lloyd 1942).

The species' root structure is fibrous, fine, and blackish, with two or three slightly divided branches from about 1.3 to 2.5 cm in length. A fugacious taproot fails to elongate, but it swells into a rounded mass covered with root hairs (Lloyd 1942). As the shoot develops, adventitious roots are put out from the stem, producing secondary rosettes, and as the stem decays, they become separated and function as asexual propagules.

The inflorescence of *Drosera anglica* is a single, one-sided, cymose raceme that terminates on a naked, glabrous scape 6 to 18 cm in height. The flowers are white, 4 to 7 mm in diameter, and radially symmetrical (actinomorphic), and 15 to 25 flowers occur on each flowering scape. The flowers are hermaphroditic and

Figure 1. Rosette of leaves and flowering scape (passing over thumb, out of frame) of a *Drosera anglica* individual in California. Photograph by Evan Wolf.

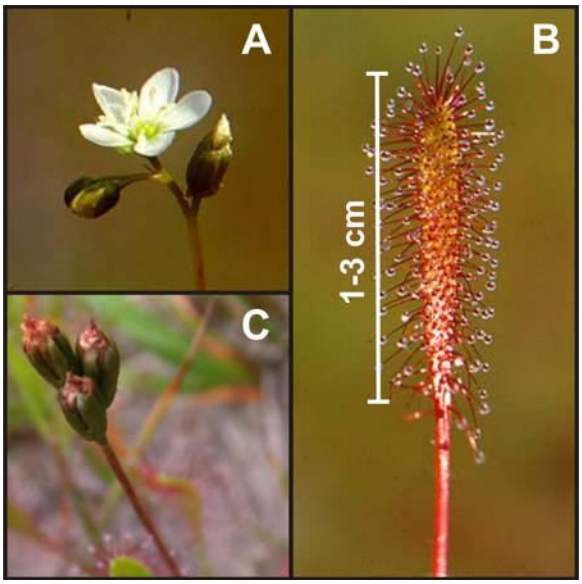


Figure 2. *Drosera anglica* flower (A), leaf and petiole (B), and mature fruit (C) (Photographs A and B by A. Anderberg; photograph C by C. Farmer). Used with permission.

have a calyx composed of a series of five united, oblong, obtuse, and imbricated sepals that are 3 to 4 mm long. The corolla is composed of five free, imbricated, entire, and spatulate petals that are 5 to 7 mm long. The androecium includes five stamens that have free, filiform filaments and yellow, extrorse anthers (Weeden 1975). The calyx, corolla, and stamens are persistent.

Pollen tetrads are 70 µm across, with single grains 54 µm, exine with spines about 3.5 µm and spinules 0.5 to 1.0 µm long (Erdtman et al. 1963, Chanda 1965). The gynoecium is described as a three part superior ovary with three free styles (Munz 1959). The plant produces a 3-valved loculicidally dehiscent capsule containing numerous black, ovoid, sigmoid-fusiform seeds 1.5 to 2.0 mm long (Abrams 1944). The fruit frequently persists entire, freeing the seeds when it rots. The seeds are spindle-shaped with a mean air-dry weight of 19 to 26 µg (Crowder et al. 1990).

Distribution and abundance

Global abundance

Drosera anglica is abundant globally, particularly in boreal regions. The species is limited to wetland habitats; however, boreal regions typically support numerous and often extensive bog and fen ecosystems conducive to *D. anglica*. Although individual populations can be relatively isolated from one another, the broad geographic distribution of the species and its local abundance have contributed to its ranking as globally secure (G5; NatureServe 2006).

The genus *Drosera* is cosmopolitan in distribution and is relatively species rich, with over 90 members described globally. The largest number of species is documented from Australia. Among carnivorous genera, only *Utricularia* boasts a greater number of species (Juniper et al. 1989). *Drosera anglica* is widely distributed, occurring in wetland habitats throughout the northern hemisphere (**Figure 3**; Hultén 1968, Schnell 2002). Compared to *D. rotundifolia*, which is the only other *Drosera* species in Region 2, *D. anglica* has a more restricted distribution in Europe, being less widespread in France and Spain, and absent altogether in Iceland. In Asia, its range is less extensive but more continuous than that of *D. rotundifolia* (Crowder et al. 1990). A significantly disjunct population occurs in Hawaii on the island of Kauai, and it appears to exhibit several different life history characteristics relative to boreal and montane populations (Mazrimas 1987).

Globally, *Drosera anglica* occurs in both maritime and continental settings and across a wide elevation range. Populations in the British Isles extend from near sea level to nearly 490 m in elevation while in the Alps they occur as high as 1,890 m (Crowder et al. 1990). The three occurrences found within USFS Region 2 are between 2,432 and 2,591 m (7,980 and 8,500 ft.) in elevation.

Drosera anglica occurs principally in peatlands, which are wetlands that accumulate peat soils over time due to decomposition rates that are slower than organic carbon input rates from primary production and allochthonous sources. **Figure 4** shows the

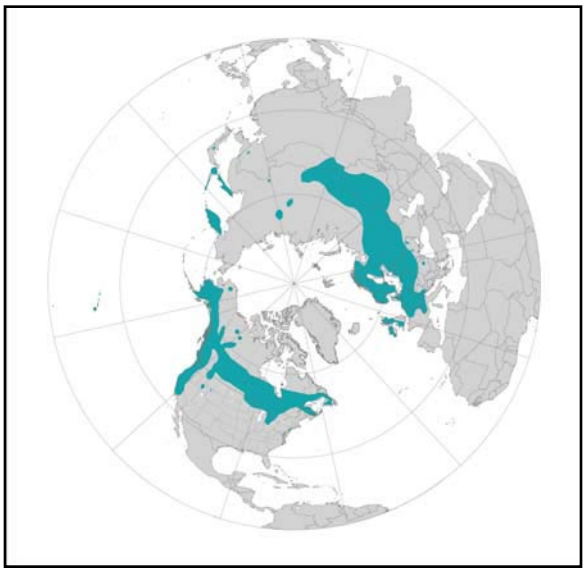


Figure 3. Hemispheric distribution of *Drosera anglica*. Populations in any given region tend to be localized to specific wetland types and can be widely separated from adjacent populations.

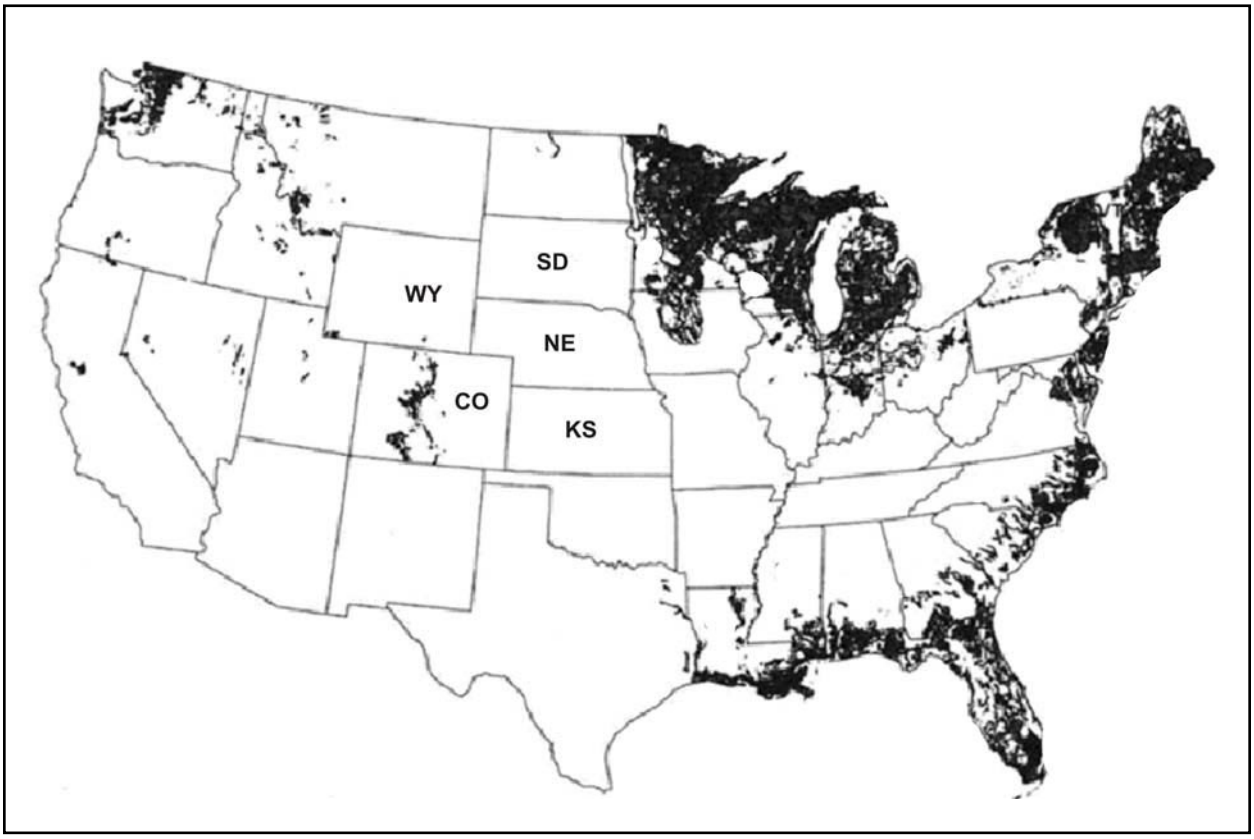


Figure 4. Distribution of main peat-forming areas in the continental United States. USDA Natural Resources Conservation Service (1999), used with permission.

main distribution of peat-forming ecosystems in the continental United States, and thus potential habitat for *D. anglica*.

USFS Region 2 abundance and population trends

No rigorous census of *Drosera anglica* occurrences has been conducted in Region 2. The anecdotal occurrence estimates associated with element occurrence and herbarium records suggest that the species is locally abundant in favorable microsites. For instance, Fertig (1997) estimated that 5,000 to 7,500 individuals were present in the Park County, WY 1 peatland, with *D. anglica* forming nearly continuous cover on floating peat mats. Densities as high as 15 to 19 individuals per square foot have been observed in favorable sites (Mills and Fertig 2000). Occurrence size estimates for the Park County WY 2 occurrence are significantly lower, on the order of 300 individuals (Wyoming Natural Diversity Database 2004). The newly discovered occurrence in La Plata County, CO is reported to have thousands of individuals (Lemly 2006 personal communication).

Because of the lack of systematic surveys conducted in *Drosera anglica* occurrences, no data are available from which to estimate population trends. Repeat visits to the two Wyoming sites suggest that occurrences are relatively stable, but absent more rigorous studies, this assessment is only conjecture.

The three known *Drosera anglica* occurrences within Region 2 are found on National Forest System lands, two on the Shoshone National Forest in Wyoming and one on the San Juan National Forest in Colorado (**Figure 5**, **Table 1**; Heidel and Laursen 2003b). Several additional occurrences are found in

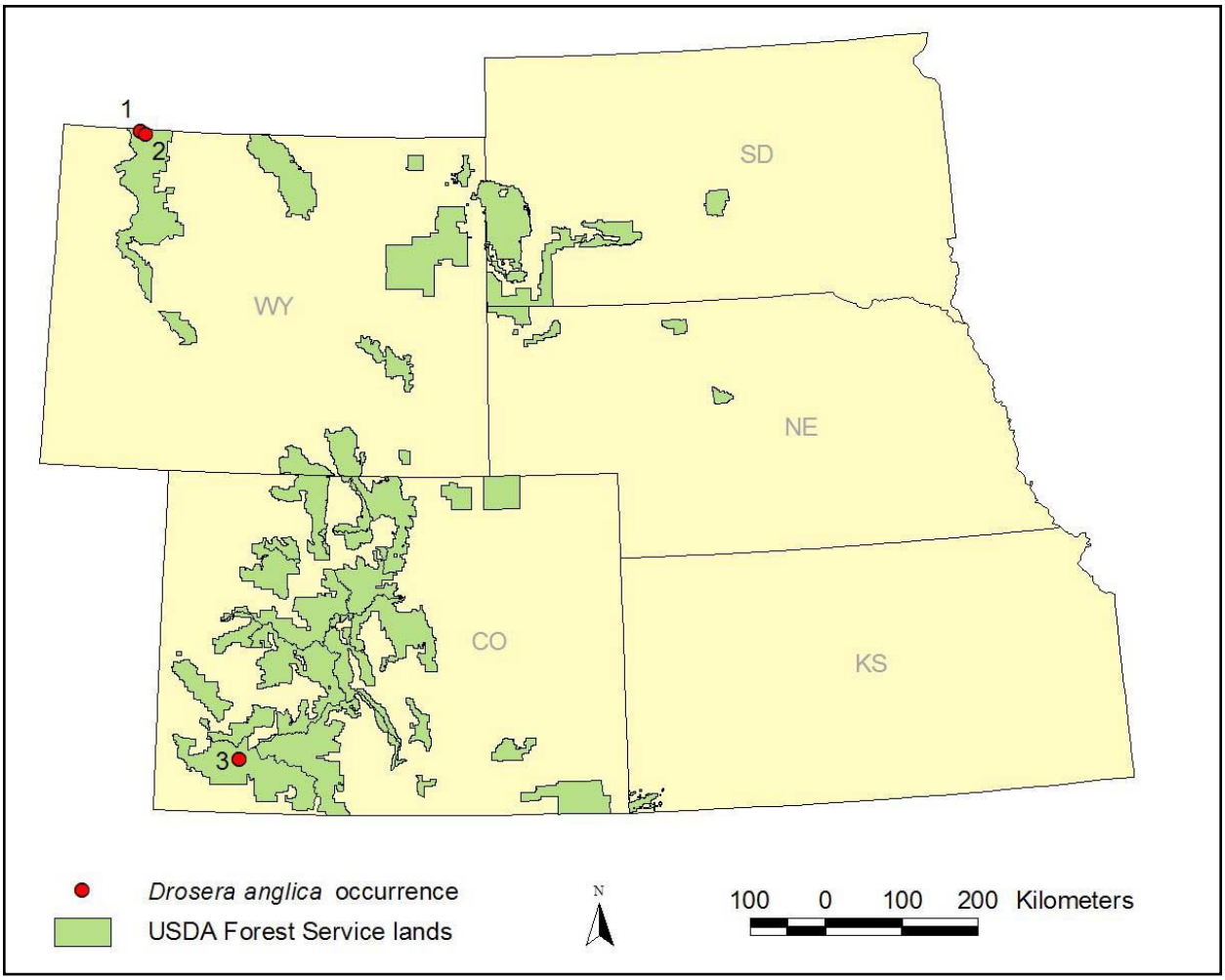


Figure 5. Distribution of *Drosera anglica* within USDA Forest Service Region 2. The occurrences numbered on the map are keyed to more detailed records presented in **Table 1** (Source data: Wyoming Natural Diversity Database element occurrence records, University of Wyoming, Rocky Mountain herbarium records).

Table 1. *Drosera anglica* occurrences in USDA Forest Service Region 2. Records are linked to Figure 5 via the "map key" field.

Map key	In-text reference	Record source	Accession/ record number	Management	Collector	Record/collection date	Elevation	Area	Last Observed	Comments
1	Park County, WY 1	Rocky Mountain Herbarium	396767, 613424, 644225	USDA Forest Service, Region 2, Shoshone National Forest	S. Mills, Walter Fertig	05-Aug-1995 27-Aug-1996	2,432 m 7,980 ft.	2.58 ha 6.38 acres	2003	Floating mat with *Carex limosa*, *C. lasiocarpa*, *Comarum palustre*, and *Sphagnum* spp.; approx. 300 plants, 95 percent of plants vegetative.
2	Park County, WY 2	Rocky Mountain Herbarium	615081	USDA Forest Service, Region 2, Shoshone National Forest	Walter Fertig	31-Aug-1996	2,463 m 8,080 ft.	5.21 ha 12.87 acres	2003	Edge of floating mat dominated by *Sphagnum* spp. with *Calamagrostis canadensis*, *Carex lasiocarpa*, and *C. limosa*; *Drosera anglica* population estimated at 5000 to 7500 plants; forms nearly continuous mats of leaves on edge of floating mats; most abundant along south bank of east pond.
3	La Plata County, CO	University of Colorado	520279	USDA Forest Service, Region 2, San Juan National Forest	Sara Brinton	23-Jul-2006	2,591 m 8,500 ft.	0.64 ha 1.58 acres	2006	Thousands of individuals growing in an oval-shaped depressional fen primarily dominated by *Carex lasiocarpa*; *Drosera anglica* occurs in a smaller, inner oval dominated by *Sphagnum* (*terres* or *squarosum*), *Viola* sp., *Lycopus asper*, and several other minor associated species (Lemly 2006 personal communication).

adjacent Yellowstone and Grand Teton national parks, as well as in Montana and Idaho (USDA Natural Resource Conservation Service 2004, Wyoming Natural Diversity Database 2004). The distribution of *D. anglica* in Wyoming includes the Yellowstone Plateau, Jackson Hole, and Beartooth Mountains in Park and Teton counties (Wyoming Natural Diversity Database 2004).

In Region 2, the fens supporting *Drosera anglica* occurrences are limited to relatively high elevations. This is likely because warmer and drier climatic conditions in the region, relative to more northern latitudes, limit peatland formation in lower elevation sites (Cooper 1996). The consistently high water tables that are necessary for peat formation and critical for the maintenance of *D. anglica* occurrences are restricted to favorable microclimatic and hydrogeomorphic settings that are of limited extent in Region 2.

Reproductive biology and autecology

Reproduction

Drosera anglica can reproduce both sexually and asexually. Asexual reproduction occurs when leaf buds form plantlets. Alternatively, axillary buds found below the rosette can form new plants, with two genetically identical individuals formed when the stem joining them decays.

Sexual reproduction is achieved almost exclusively through self-pollination of the hermaphroditic flowers (Engelhardt 1998). Cross-pollination and genetic recombination are rare, so nearly all reproduction – vegetative or sexual (seeds) – results in offspring that are either genetically identical to the parent (via vegetative reproduction) or that contain an equal, or slightly reduced, genetic variability compared to the parent generation (via sexual self-pollination).

Life history and strategy

Drosera anglica, like other carnivorous plants (as defined by Givnish 1984), derives a significant proportion of its nutrients, most importantly nitrogen, from the absorption of animal tissue. The independent evolution of carnivory in multiple, diverse plant families suggests that it is an adaptation to the nutrient poor habitats where carnivorous plants are found (Givnish et al. 1984). This adaptation to attract and consume insects is physiologically costly, however (Thoren et al. 2003), and the photosynthetic cost of the investment in carnivory is only offset in bright, wet settings. Thus in sunny, water-saturated, low nutrient environments, carnivory confers an important competitive advantage in the ability to obtain nutrients without an overwhelming cost to photosynthesis (Ellison and Gotelli 2001).

Drosera anglica can capture and digest a wide range of arthropods. In a study of prey captured by different *Drosera* species, *D. anglica* trapped individuals from over 13 different arthropod orders, with Dipterans being the most common prey type (**Figure 6**).

Studies to determine the proportion of carnivory-derived nitrogen within *Drosera rotundifolia* and *D. intermedia*, both morphologically similar to *D. anglica*, have produced values ranging from 26.5 percent (Schulze and Schulze 1990) to 50 percent (Millett et al. 2003). The increased consumption of nitrogen that carnivory provides has been shown to benefit plant growth, flowering, and seed production; it does not, however, produce an increase in the rate of photosynthesis (Mendez and Karlsson 1999).

Charles Darwin (1878) showed that flower and seed production in *Drosera* spp. increased with artificially elevated feeding rates. Other investigations have corroborated the correlation between increased prey consumption and increases in growth (Thum 1988, Krafft and Handel 1991, Thoren and Karlsson 1998). However, the closely related *D. rotundifolia* can grow, survive, and reproduce in the absence of prey. One study found that there was no difference in growth between plants where insects were excluded and those that trapped prey (Stewart and Nilsen 1992). The study was conducted in a relatively high-nutrient peatland, and it is likely that their findings indicate that this *D. rotundifolia* occurrence is not nutrient limited. This study appears to be the exception in a wide array of literature that demonstrates that the nitrogen derived from carnivory aids plant growth at the time of capture and into the future. An estimated 24 to 30 percent of the nitrogen stored over winter in the hypocotyl of *D. rotundifolia* leaves originated from insect capture during the previous growing season (Schulze and Schulze 1990).

While *Drosera anglica* (and other carnivorous plants) may be able to subsist for the duration of a scientific study without the nutrients absorbed from insects, their long-term, evolutionary strategy for survival apparently depends on carnivory (Ellison and Gotelli 2001).

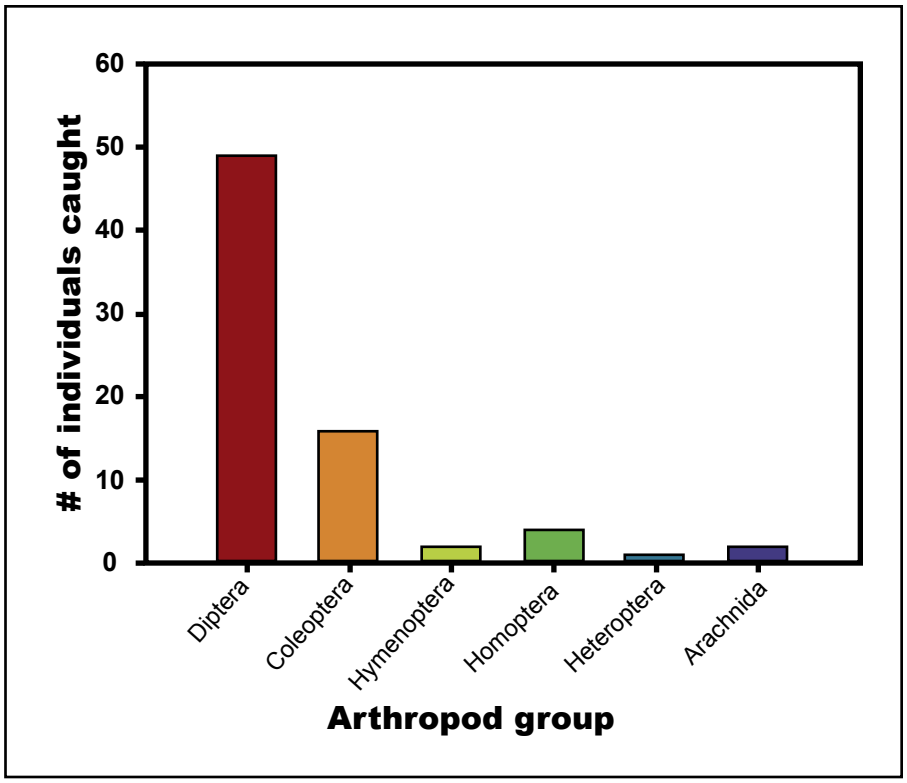


Figure 6. Arthropod composition of the prey captured by *Drosera anglica* (Achterberg 1973, in Juniper et al. 1989). Used with permission.

Pollinators and pollination ecology

Drosera anglica is an autogamous (self-pollinating) species. Throughout most of its range, the flowers of *D. anglica* never open, and these plants reproduce through cleistogamy (self-pollination within unopened flowers; Crowder et al. 1990). Chasmogamous flowers (open flowers with exposed reproductive structures) do occur, but they are only open for about two hours during the brightest sunlight for each of the three to seven days that they persist (Engelhardt 1998). The stigmas and anthers of open flowers are often intertwined or in close proximity, potentially enhancing the possibility of autogamy (Murza and Davis 2003).

Pollen to ovule ratios and observation data regarding pollinator visitation indicate that little to no cross-pollination occurs via wind dispersed pollen or entomophily (insect pollination) (Murza and Davis 2003). All reported pollen to ovule ratios are low and fall within the ranges reported for cleistogamy and autogamy (Cruden 1977). Low pollen ratios indicate a pollination strategy that does not rely on transporting pollen between flowers, which is a low probability event for which copious pollen is beneficial. Additionally, *Drosera anglica* does not possess functional nectaries, which would serve to attract insect pollinators. A study of insect visitation to a chasmogamous occurrence in California reported no activity in *D. rotundifolia* flowers that would result in pollen transport (Engelhardt 1998).

Dispersal mechanisms

Drosera anglica has no specific long-distance dispersal mechanism, but may be distributed by flowing water, wind, or animals. The seeds are able to float for a week to several months on a water surface, owing to trapped air within their testa (Ridley 1930, Swales 1975, Crowder et al. 1990, Engelhardt 1998). Their low weight allows them to be blown a short distance by gusts of wind. Foraging animals such as deer, bear, or birds may ingest seeds and defecate them at a different location. The small, light seeds may also stick to bird feet or feathers, or mammal fur as they move past the plant (Crowder et al. 1990).

Seed viability and germination requirements

No persistent soil seed bank has been reported for *Drosera anglica* (Nordbakken et al. 2003). The viable period of *D. rotundifolia* has been described as up to four years (McGraw 1986, Poschlod 1995), and it is very likely that *D. anglica* seeds persist in the soil in a similar fashion. The seeds of *D. anglica* go dormant and

have similar dormancy-breaking requirements as other *Drosera* species (Baskin et al. 2001). Germinability of *D. anglica* seeds following cold stratification is similar to *D. rotundifolia*. The highest germination rate (90 percent) for *D. anglica* seeds was achieved with seed in moist, dark storage at 10 °C for eight weeks, and then kept in a greenhouse with 14 h of daylight between 18 and 22 °C. The optimal germination conditions for maximum seedling survival were light, wet storage and 16 weeks of cold treatment followed by alternating warm temperatures (Crowder et al. 1990).

The germinability of *Drosera rotundifolia* seeds, which are very similar in size and morphology to those of *D. anglica* (Wynne 1944), rapidly decreases with burial depth (**Figure 7**; Cambell and Rochefort 2003). Thus, seeds in the soil seed bank that are at the surface or brought to the surface by disturbance are much more likely to germinate.

Cryptic phases

Drosera anglica passes through two life stages that may be considered cryptic: dormant seeds (Crowder et al. 1990) and over-wintering dormant buds, called hibernacula (**Figure 8**). The soil seed bank may be especially important in recolonization following disturbance (Jacquemart et al. 2003). Hibernacula are formed beginning in July and consist of two to eight spirally inrolled leaves wrapped in divided stipules. Over the winter, the remains of the previous summer's leaves surround the hibernacula. The onset of cold temperatures triggers dormancy, and warm temperatures rejuvenate growth (Crowder et al. 1990).

Mycorrhizal relationships

There are no known mycorrhizal relationships with *Drosera anglica*.

Hybridization

Drosera anglica has 40 diploid chromosomes (2n = 40), whereas all other northern *Drosera* species have 20. This condition, called amphiploidy, may have resulted from the complete combination of the chromosomes of *D. rotundifolia* and *D. linearis* (Wood 1955). These two species commonly cross-pollinate in nature to form the sterile hybrid *D.* x *anglica* (2n = 20). Chromosome doubling may have occurred in this

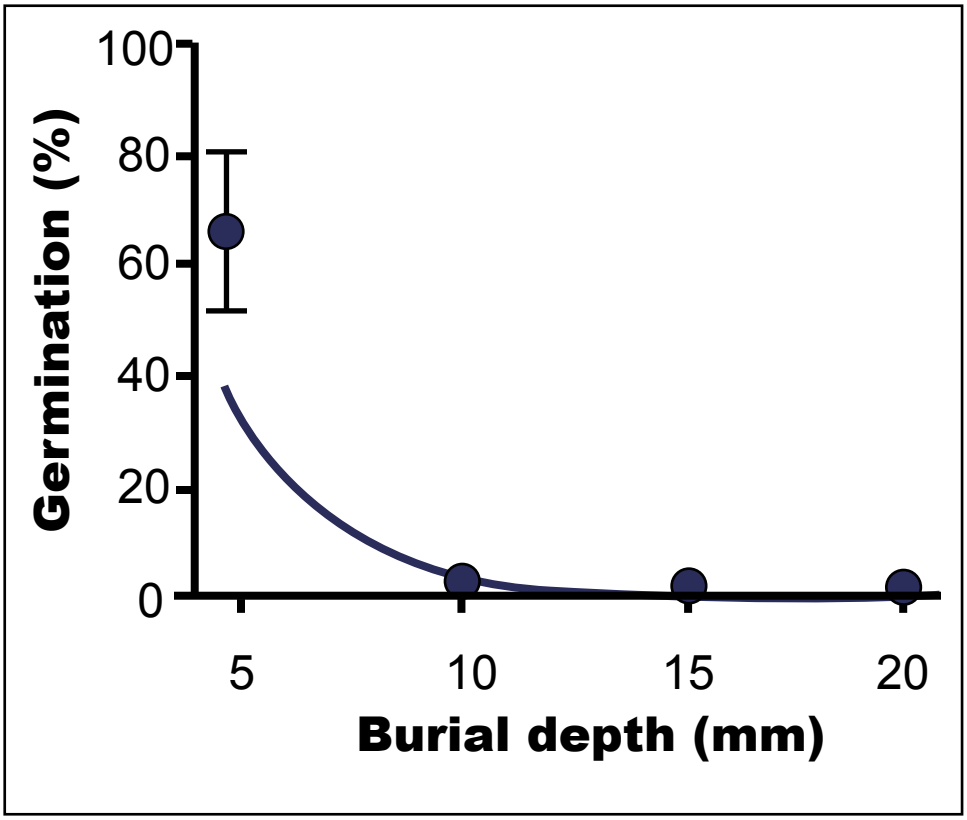


Figure 7. Seed germination in relation to burial depth for *Drosera rotundifolia*. (Modified from Cambell and Rochefort 2003). Used with permission.

Figure 8. Hibernacula of *Drosera anglica* (ICPS 2006). Used with permission.

normally sterile hybrid to create the fertile amphiploid, *D. anglica*.

Several lines of evidence support the assertion that *Drosera anglica* arose from hybridization. The original claim was made based on chromosome number (Winge 1917); subsequent evidence based on leaf morphology (Wood 1955), the existence of naturally occurring hybrids (Gervais and Gauthier 1999), isoenzyme similarities (Seeholzer 1993), and very similar chloroplast *rbcL* nucleotide sequences (Rivadavia et al. 2003) supports this idea. Conversely, two studies provide evidence contrary to the hybrid-origin hypothesis. Murza and Davis (2003) studied floral structure and showed that there are many differences between the three species. In a cytological study, a bimodal karyotype was expected because hybrid origin was assumed, but none was detected (Hoshi and Kondo 1998). While there is some doubt as to the evolutionary history of *D. anglica*, most of the evidence points to a hybrid, amphiploid origin.

Although chasmogamous flowers are rare, they do occur and allow *Drosera anglica* to cross with other *Drosera* species in nature to produce sterile hybrids. *Drosera* x *obovata* Mert. and Koch (2n = 30) is a cross between *D. anglica* and *D. rotundifolia* and occurs in the United States in California, Oregon, Washington, and Minnesota. A cross between *D. anglica* and *D. linearis*, called *D.* x *linglica* Kusakabe ex Gauthier and Gervais (2n = 30), has been found in the wild in Michigan (Schnell 1995) and Quebec (Gervais and Gauthier 1999).

Since neither *Drosera rotundifolia* nor *D. linearis* has been found to occur within 100 miles of known Region 2 *D. anglica* occurrences, hybridization is unlikely within Region 2.

Demography

The only demographic data available for *Drosera anglica* in Region 2 are the estimates of the number of individuals in each occurrence, which are addressed in the above USFS Region 2 Abundance and population trends section.

Mortality is strongly size dependent; it is high for seedlings, low for the smallest mature rosettes, and high for the largest mature rosettes. In a Norwegian population of *Drosera anglica*, more than half of the plants were seedlings, and seedling mortality ranged from 45 to 85 percent (Nordbakken et al. 2004). This high mortality likely resulted from the very shallow roots of the seedlings being unable to acquire sufficient water from a dynamic water table. In addition to the ability of rosettes to become established, another important population growth factor for *D. anglica* is the ability of mature plants to survive. Since mature plants live up to five years and rosette size is positively correlated with age (Crowder et al. 1990), high mortality rates in large individuals probably occur because they have reached their maximum lifespan.

Larger plants produce most of the viable seed, i.e. fecundity is positively correlated with rosette size. During the five years of observation in the Norwegian study, mortality and fecundity varied greatly between years. Temporal variation was much greater than variation along the studied gradients of depth to water table and peat-producing ability (similar to primary productivity) (Nordbakken et al. 2004).

The demographic study of *Drosera anglica* (Nordbakken et al. 2004) and observations of a related species, *D. rotundifolia*, at a site in Colorado (Rocchio and Stevens 2004) indicate that the number of individuals in an occurrence is highly variable between years. In the Norwegian study, a wetter than average growing season caused a two- to three-fold reduction in population growth rate. The qualitative observations in Colorado indicate a 100-fold decrease in the number of individuals at a site between two consecutive years. This could be due to increased visitor use and trampling that corresponded to that same time period, or it may be the result of a cool and wet growing season during 2004, the second year of observation (Wolf et al. 2006).

Whatever the causes may be, *Drosera anglica* and related species experience large interannual fluctuations in numbers of individuals at occurrences. This high degree of variability, which is probably partly, if not mostly, due to stochastic climatic episodes, indicates that preservation of a large number of individuals at each occurrence is necessary for population viability. Extrapolating generalized minimum occurrence sizes from population viability studies of other ecosystems, species, and climatic regions would be unwise. Given the few number of occurrences within the region and the lack of basic quantitative demographic data for any of them, the first step of a population viability analysis, collecting repeatable measurements of the number of individuals at each site, is critical and should be relatively quick and easy.

Life history characteristics

Four main life stages have been identified for *Drosera anglica*: 1) seed, 2) seedling, 3) mature plant, and 4) vegetative propagule. In addition to these four primary stages are two dormant (or cryptic) phases, the soil seed bank and the overwintering hibernacula. The transitions between these six life stages are depicted in **Figure 9**, which summarizes the life stages and processes discussed in the preceding sections. Since first-year seedlings do not reproduce (Nordbakken et al. 2004), they must spend one year growing and overwintering (as hibernacula) and then re-emerge as mature plants capable of reproduction.

Ecological influences on survival and reproduction

Within fen and bog settings where *Drosera anglica* occurs, temporal and spatial fluctuations in water availability and competition with other plants can significantly influence the growth and survival of the species. In a Norwegian study of *D. anglica*, temporal variation in climate had a more significant influence on population growth rate than plant position along two major environmental gradients, depth to water table (DWT; **Figure 10**) and peat production ability (PPA; **Figure 10**). The low growth rate during the second one-year-period (OYP 2; 1996-1997) was caused by higher mortality of mature rosettes and lower than normal fecundity, apparently brought about by unfavorable climatic conditions. These conditions included two growing season months (May and August, 1997) with over 200 percent of normal precipitation. It is possible that such increases in water may dilute what little nutrients are available to bog and fen plants and thus reduce their fitness. Wetter than average years may also increase the depth and duration of inundation and lead to flooding-related mortality, such as anoxia. Additionally, cooler than normal temperatures may

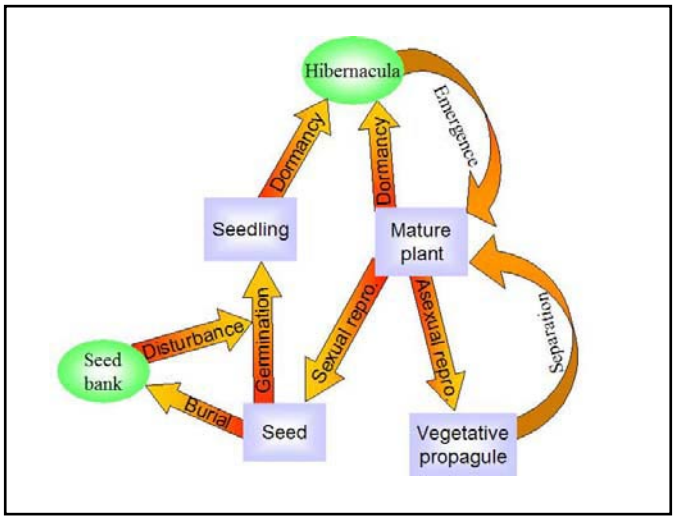
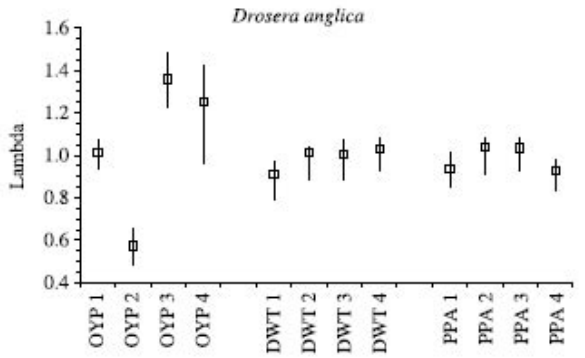


Figure 9. Life cycle diagram for *Drosera anglica*.



Reference number	OYP	DWT	PPA
1	1995–96	–2.8–1.9	0–1.546
2	1996–97	2.0–3.9	1.547–1.600
3	1997–98	4.0–6.8	1.601–1.677
4	1998–99	6.9–19.3	1.678–2.000

Figure 10. Population growth rate (λ; +99% confidence intervals) for each of four (reference numbers 1 to 4) one-year-periods (OYP), quartiles for depth to water table (DTW, cm), and peat production ability (PPA) (from Nordbakken et al. 2004). Used with permission.

reduce the availability of insect prey (Nordbakken et al. 2004).

Nordbakken et al. (2004) found significant differences in growth rates along both of the environmental gradients although they were less important than the previously mentioned temporal variation. Moderately-productive peatlands (PPA classes 2 and 3) appear to be the most favorable classes within the gradient because they represent the optimal balance between water supply (which is less regulated in low productivity sites with poor capillary rise) and burial by *Sphagnum* moss growth in highly productive sites. The slightly lower population growth rate of *Drosera anglica* in the wettest water table class that includes a water table above the ground surface (DWT class 1; -2.8 to 1.9 cm) indicates a sensitivity to complete inundation in hollows. Although *D. anglica* is more tolerant of flooding than *D. rotundifolia*, this is evidence that complete inundation by water is detrimental to its growth. It is possible that inundation may not be the direct cause of lower growth rates, but it may facilitate other damage to the plant such as erosion, ice damage, and overgrowth by algae (Nordbakken et al. 2004).

Episodic unfavorable climate conditions regulated *Drosera anglica* growth in ombrotrophic bogs in Norway. Species occurrences only rarely and locally reach sufficient concentrations where density-dependent birth and mortality rates regulate populations (Nordbakken et al. 2004).

Genetic characteristics and concerns

No studies of the genetic characteristics of Region 2 *Drosera anglica* occurrences have been conducted. However, a study of the genetic variability of *D. rotundifolia* occurrences in Colorado and California found little genetic variation among and within occurrences (Cohu 2003). This lack of variability within occurrences would be expected for species whose primary mode of reproduction is asexual, such as *D. rotundifolia* and *D. anglica*, due to a lack of genetic recombination. Since the Region 2 *D. anglica* populations are similarly disjunct, it is likely that the results of a genetic analysis would be similar to that of *D. rotundifolia*.

The DNA and RNA of *Drosera rotundifolia*, a close relative to *D. anglica*, can be extracted using a relatively simple technique (Bekesiova et al. 1999). The ability to isolate and analyze genetic material, which has the potential to produce agriculturally useful traits and medically important chemicals, underscores the need for a better understanding of the natural genetic variability within and among populations of *D. anglica*, in order to preserve critical genetic resources (Kamarainen et al. 2003).

Genes from a species similar to *Drosera anglica*, *D. rotundifolia*, have been used to genetically engineer carnivorous traits in potato plants (Associated Press 1999) with the hope that the trapping tentacles will provide both pest protection and extra nitrogen for agricultural species. Since it is likely that half of the 40 chromosomes of *D. anglica* originated from *D. rotundifolia*, it too may be a source of this genetic material. However, the significant physiological costs to an agricultural plant of growing and maintaining such specialized structures may outweigh their benefits (Ellison and Gotelli 2001).

Drosera anglica produces the chemicals 7-methyljuglone and plumbagin, both of which are napthaquinones. The specific function of these secondary compounds in *D. anglica* is unknown, but napthaquinones are known to be antifungal, antibiotic, antiviral, and allelopathic (Gu et al. 2004). For humans, these compounds have potential for use in chemotherapy, but they may be carcinogenic. The chemicals create superoxides, which are toxic to certain bio-molecules. It is unclear whether 7-methyljuglone and plumbagin have a great enough margin of safety for pharmacological use, so they have been nominated for further medical study (National Institute of Health 2000). Extracts from *D. anglica* and other *Drosera* species have long traditions of use as folk medicines.

Factors limiting population growth

Habitat availability and climatic conditions (i.e., moisture, temperature) are the primary controls of *Drosera anglica* occurrence size and growth. Occurrences are rarely and only locally regulated by density-dependent recruitment and mortality rates (Nordbakken et al. 2004).

Community and ecosystem ecology

General habitat characteristics

Drosera anglica is an obligate wetland species that requires continuously moist or saturated soils (Reed 1996) and is found in sites with shallow water table depths. The roots cannot tolerate desiccation, and the rooting zone (<6 cm below ground surface) must remain moist to saturated. *Drosera anglica* can withstand ground frost with its leaves uncurled, and this occurs often within its boreal distribution (Crowder et al. 1990). The species occurs in both continental and maritime climates (Haslam 1965, Glaser 1987, Glaser 1987, Hotes et al. 2001). The plant prefers full sun and does not tolerate shading or overgrowth by *Sphagnum* (Crowder et al. 1990).

Throughout its range, *Drosera anglica* is typically found in peatlands including ombrotrophic bogs, rich and poor fens (Juniper et al. 1989, Crowder et al. 1990, Schnell 2002). Although typically occurring in acidic environments, the species is also known from intermediate-rich and extreme-rich fens, which have circumneutral to slightly basic pH, and occasionally from wetlands with mineral, as opposed to organic, substrates (Szumigalski and Bayley 1997). Only a few other *Drosera* species are tolerant of calcium-rich sites, and they include *D. linearis* (found in the United states in Montana, Minnesota, Wisconsin, Michigan, and Maine), *D. falconeri* (northern Australia), and *D. erythrorhiza* (western Australia).

Peatlands, where *Drosera anglica* is typically found, are formed in areas of perennial water saturation. Peat accumulates because the rate of primary production exceeds that of decomposition, allowing a net increase in organic carbon material in the soil in the form of peat. The slow rate of decomposition is a result of the cold, anoxic environment in a groundwater-saturated soil. Slow decomposition rates result in very low amounts of plant-available nitrogen and phosphorous in the soil. In areas where the soil dries out for a significant time each year, the organic matter is exposed to oxygen and decomposes, and peat will not be formed. *Drosera anglica* is intolerant of desiccation and performs poorly in sites with high amounts of plant-available nitrogen, restricting it almost exclusively to peatlands (Juniper et al. 1989).

Bogs and fens, the two major types of peatlands, form from different hydrologic regimes. True bogs, which are ombrogenous (rain generated) and ombrotrophic (rain fed), are hydrologically supported solely by precipitation, and they receive nutrients largely through wet and dry atmospheric deposition. Fens are formed by stable water levels regulated by groundwater discharge. This groundwater has been in contact with bedrock and mineral sediment and contains various amounts of dissolved nutrients, typically more than is present in a bog.

Consequently, bog habitats are oligotrophic with respect to nutrient availability and support species adapted to nutrient-poor conditions (Damman 1986, Crum 1988, Vitt et al. 1995). *Sphagnum* moss species typically dominate the ground cover (Glaser et al. 1981, Andrus 1986), and their ability to actively exchange ions

is a significant control on the pH, nutrient availability, and floristic composition of most bogs and fens (Andrus 1986, Mitsch and Gosselink 2000).

Wetlands in general and peatlands in particular, only form in specific hydrogeomorphic and climatic settings. In environments such as the boreal regions, with high precipitation and low evapotranspiration rates, peatlands that range from ombrotrophic bogs to minerotrophic fens can be a significant or even dominant cover type on the landscape (Zoltai et al. 1988). However, at lower latitudes including most of Region 2, peatlands are constrained to very specific geomorphic and landscape settings that possess the hydrologic and microclimatic conditions necessary to support peat accumulation (Cooper 1996). Winter snow and summer rain recharge hillslope aquifers, which discharge consistently throughout the long warm summer, maintaining saturated, anoxic, peat accumulating conditions. However, *Sphagnum*-dominated fens are found in the ecoregion, and these share many floristic elements with ombrotrophic bogs and fens, including the occasional presence of *Drosera anglica*.

There are four principal landform configurations that produce groundwater discharge systems capable of supporting fens in the mountain regions of the western United States: 1) discrete hillslope springs controlled by bedrock fractures/contacts, 2) upwelling springs, 3) closed basins and, 4) open-basin hillslopes.

At discrete springs, groundwater is discharged on hillslopes where a fracture system or bedrock contact is exposed at the surface. If the springs are associated with a sufficiently large aquifer, the discharge may be perennially stable and support a fen (**Figure 11**).

Springs often form at or near the toe of hillslopes where coalescing groundwater flow paths cause water to reach the ground surface. If fen vegetation completely overgrows and contains an upwelling spring, the entwined mat of roots and peat will hold the vertical hydraulic pressure of the emerging water, forming a spring mound (**Figure 12**).

In closed basins where groundwater discharge collects in a lake, floating vegetation mats can form starting at the lakeshore or on fallen logs and encroach inward. Fens may grow a short distance up the shore slope if the capillary fringe and/or upslope springs provide sufficient perennial water (**Figure 13**).

Finally, fens most commonly form at discrete springs associated with bedrock fractures or contacts or on sloping surfaces near the base of hillslopes where groundwater discharge coalesces but does not form a perennial lake. Hillslope aquifers, often in unconsolidated material such as talus or glacial till, may store sufficient groundwater to produce steady, diffuse discharge that supports fen formation (**Figure 14**).

The Park County, WY 1 and Park County, WY 2 *Drosera anglica* occurrences are on floating mats in

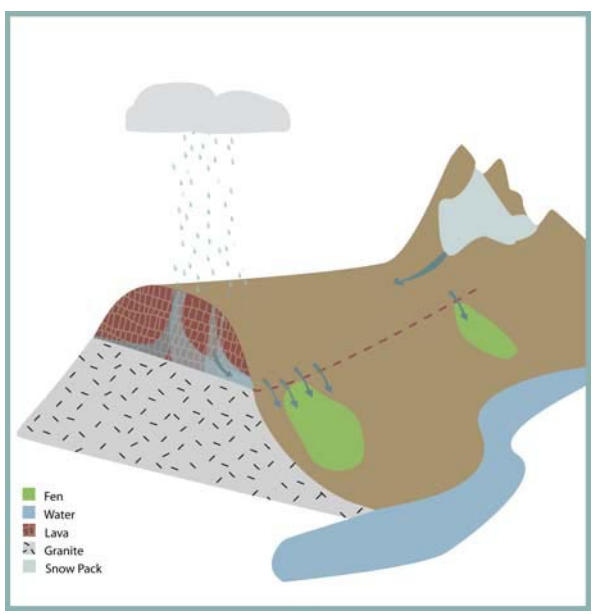


Figure 11. Illustration of hillslope fens associated with a bedrock contact (shown in cutout) or a bedrock fracture (indicated by dashed red line).

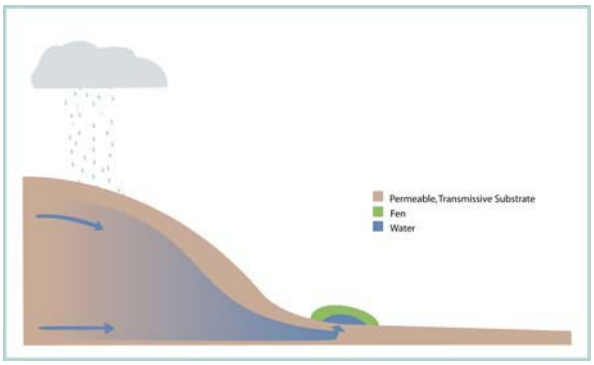


Figure 12. Illustration of upwelling groundwater at the toe of a hillslope supporting a spring mound fen.

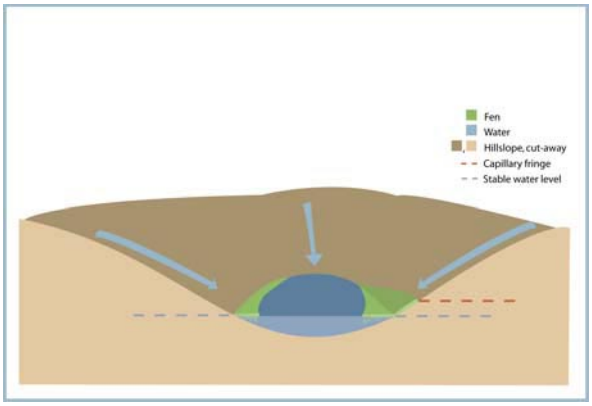


Figure 13. Illustration of a closed basin where groundwater feeds a lake that supports a floating mat fen.

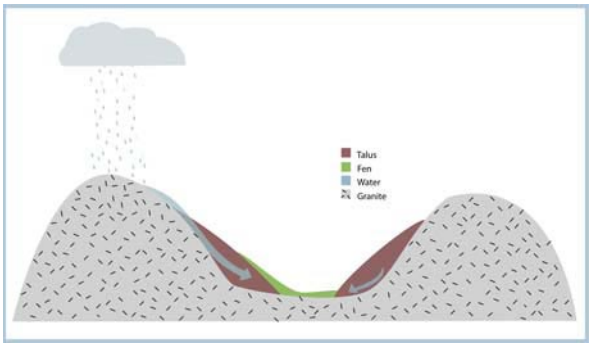


Figure 14. Illustration of sloping fen that formed where groundwater flow is concentrated.

mostly-closed basins (**Figure 13**). The La Plata County, CO occurrence is in a closed basin fen that may be a filled-in lake where a floating mat has completely covered all open water.

Substrate characteristics and microhabitats

Drosera anglica typically grows on wet peat or *Sphagnum*. It is less tolerant of desiccation than *D. rotundifolia*, so it does not thrive on raised hummocks as *D. rotundifolia* often does (**Figure 15**). Although it can tolerate inundation, it does not typically form dense mats in pools as *D. intermedia* does. *Drosera anglica* occupies the middle niche of the depth to water gradient, with *D. rotundifolia* preferring drier sites, and *D. intermedia* selecting wetter sites. The microhabitat of *D. anglica* is typically a *Sphagnum* lawn with a water table at or a few centimeters below the surface. Occasionally, however, *D. anglica* is not found on *Sphagnum* lawns. It has been observed on floating logs, lake sands, and river gravels (often calcium rich) and was found once on calcareous tufa (Juniper et al. 1989, Crowder et al. 1990).

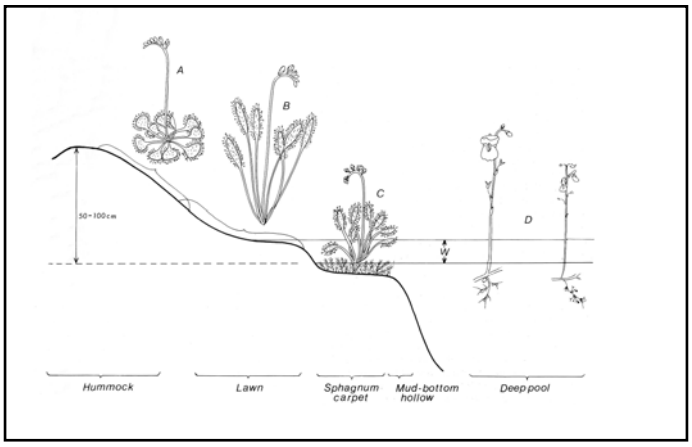


Figure 15. The local distribution of northern European *Drosera* in a blanket bog. (A) *D. rotundifolia*; (B) *D. anglica*; (C) *D. intermedia*; (D) *Utricularia vulgaris* and *U. minor* (aquatic carnivorous plants); (W) fluctuating water level (from Juniper et al. 1989). Used with permission.

USFS Region 2 habitat characteristics

Drosera anglica in Region 2 occurs only on living *Sphagnum* moss and peat generated by *Sphagnum* moss. At both sites on the Shoshone National Forest, *D. anglica* is found on floating mats at the margin of open water. The two occurrences, Park County, WY 1 and Park County, WY 2, are wetlands at the margins of glacial kettle ponds. Some of the other numerous kettle ponds in the area have filled in partly or completely with sediment and/or organic matter (Fertig and Jones 1999). The La Plata County, CO *D. anglica* occurrence is on a sphagnum substrate in the center of a basin fen that may be a filled in pond (Lemly 2006 personal communication).

The Park County, WY 2 wetland is located within a basin to the northeast of a small lake, 5.21 hectares in area at 2,463 m elevation. It supports a large *Drosera anglica* occurrence on a floating mat that borders two small, unnamed ponds (**Figure 16** and **Figure 17**). The small basin was once a lake, but now the open water pools occupy less than 40 percent of the area. The basin has an outlet that drains to a small lake and is surrounded by *Pinus contorta* (lodgepole pine) forest and granite outcrops (Heidel and Laursen 2003a).

The Park County, WY 2 wetland is a poor fen, with water pH of 4.3 to 5.0. The mat forming vegetation is *Sphagnum* spp., *Carex limosa*, and *Menyanthes trifoliata*. Encircling the wetland is a thin line of willow (*Salix* sp.), and Labrador tea (*Ledum glandulosum*) grows on raised hummocks within the fen. *Carex lasiocarpa* and *C. vesicaria* dominate the rest of the peatland (Heidel and Laursen 2003a).

The Park County, WY 1 wetland is a 5.28 ha poor fen on the shores of a small lake at 2,432 m elevation.

Figure 16. Oblique photograph of the Park County, WY 2 wetland, Shoshone National Forest, WY (Photograph by W. Fertig, source: Heidel and Laursen 2003a). Used with permission.

Figure 17. Floating mat at the Park County, WY 2 wetland, Shoshone National Forest, WY (Photograph by W. Fertig, Source: Heidel and Laursen 2003a). Used with permission.

The *Drosera anglica* occurrence at this site is on a floating mat on the perimeter of the lake. There are no flowing surface water inlets or outlets in the basin. *Pinus contorta* and open meadows surround the lake. The water of the Park County, WY 1 fen has a pH of 4.9 to 5.5 and supports poor fen vegetation. The floating mat is formed from *Sphagnum* spp., *Carex limosa*, and *Menyanthes trifoliata*.

The La Plata County, CO wetland is a 0.64 ha basin fen at 2,591 m elevation. The *Drosera anglica* occurrence at this site occupies a small oval in the central area of the fen. *Sphagnum* moss is abundant in this central oval with a moat of standing water with *Carex utriculata* surrounding it.

The water at the La Plata County, CO site has a pH of 5.02 to 5.39 and supports poor fen vegetation. Some of the dominants include *Carex lasiocarpa*, *Menyanthes trifoliate*, *Rhynchospora alba*, and *Viola macloskeyi*.

Because floating mats rise and fall with pond water levels, the water table within the mat remains constant throughout the year. Floating mats are highly susceptible to degradation, and they only develop in small ponds that do not have significant wave action. Floating mats are isolated from valley margins and do not directly receive inflowing groundwater. They are saturated by capillary rise from the pond water, and the floating mat peat has very slow water flux rates. Thus, the influx of mineral ions and nutrients is very low, and *Sphagnum* mosses can create localized acid conditions, even where the fen's water sources are neutral in pH.

Floating mats are also isolated from mineral sediment inputs resulting from hillslope erosion, further limiting ion and nutrient delivery processes. Very few species are adapted to this perennially-saturated, and ion and nutrient poor acid environment, creating relatively little competition for *Drosera anglica*. Some floating mats are close enough to forest margins that falling trees may reach the mats and become incorporated into the mat itself. In California, dense populations of *D. anglica* have been observed clustered around downed logs on floating mats. The structure and microhabitat produced by these downed logs may be critical to the maintenance and diversity of some floating mat systems (personal observation).

Water and peat chemistry

The importance of fens to regional and local biodiversity is well known. Fens support many rare plant and animal species and unique communities (Cooper 1991, Fertig and Jones 1992, Cooper 1996, Cooper and Sanderson 1997). The mineral ions and nutrients that most fen plants depend upon are supplied by their water sources. Consequently, the geochemistry of bedrock and quaternary deposits in contributing watersheds are key controls of the fen pH and nutrient and ion delivery (Glaser et al. 1981, Windell et al. 1986, Chee and Vitt 1989).

Watersheds with limestone, dolomite, or shale bedrock produce water that is basic in reaction (pH 7.0 to 8.5; Cooper 1996, Chapman et al. 2003) while those composed of granitic or metamorphic rocks produce acidic waters (Cooper and Andrus 1994, Cooper 1996). In addition, the acids in bogs and poor fens are produced during cation exchange by *Sphagnum* mosses (Cooper et al. 2002).

Water chemistry data from studies throughout the world indicate that *Drosera anglica* favors acidic and

low nutrient habitats, but there are exceptions (**Table 2**). A Norwegian study found that pH of extracted pore waters usually range from 3.5 and 4.5, but may be as high as 6.6 (Nordbakken et al. 2004).

Wetland hydrology

In nutrient-poor peatlands, the water table gradient is by far the most important determinant of species composition (Nordbakken et al. 2004). Of significant, but lesser importance, are the peat productivity gradient (Nordbakken et al. 2004) and grazing intensity (Cooper et al. 2001). Nordbakken et al. (2004) observed that more than 90 percent of *Drosera anglica* plants were found where the water table was between 1 cm above the ground surface to 7 cm below ground. The median water table depth below the surface was 4.0 cm, and the plant preferred sites in the middle of the peat productivity gradient (Nordbakken et al. 2004).

While *Drosera anglica* individuals can survive complete inundation for up to two months (Crowder et al. 1990), they are less fit in flooded conditions (Norbakken et al. 2004). Germination and growth generally start while spring melt water covers the peatland surface. In floating mat sites, which represent the primary environment supporting Region 2 occurrences, hydrologic conditions are typically fairly stable despite fluctuations in lake levels, as the mat is capable of floating up or down.

Vegetation associations and associated plant species

Species composition of floating mats varies, but typically includes *Sphagnum* mosses (*S. teres* and *S. angustifolium* at Park County, WY 2 and *S. warnstorfii* [at Park County, WY 1]), sedges such as *Carex limosa* and *C. lasiocarpa*, and herbaceous dicots such as *Menyanthes trifoliate*. Dominant species at the Park County, WY 2 fen include *C. lasiocarpa*, *C. limosa*, *C. vesicaria* (blister sedge), *M. trifoliata*, and *Ledum glandulosum*. In addition to *Drosera anglica*, several other rare plants occur at Park County, WY 2: *C. diandra*, *Eriophorum gracile*, and *Potamogeton praelongus* (Heidel and Laursen 2003a).

The Park County, WY 1 occurrence, approximately 5.4 km from the Park County, WY 2 occurrence of *Drosera anglica*, supports a slightly different suite of plants. Dominant species include *Carex limosa*, *Menyanthes trifoliata*, *C. utriculata*, *Salix planifolia*, and *C. aquatilis*. Additional rare plants, other than *D. anglica*, include *C. diandra*, *C. leptalea*, *S. farriae*, *Eriophorum gracile*, and *Potamogeton praelongus* (Heidel and Laursen 2003a).

Plants at the La Plata County, CO occurrence include *Calamagrostis canadensis*, *Carex buxbaumii*, *C. interior*, *C. lasiocarpa*, *C. utriculata*, *Epilobium hornemannii*, *Eriophorum angustifolium*, *Galium*

Table 2. Comparison of water pH and calcium (Ca^{2+}) and magnesium (Mg^{2+}) ion concentrations measured in wetlands with *Drosera anglica*. N/A= Not Available.

Reference	Study location	pH	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)
Region 2				
Heidel and Laursen 2003	Shoshone National Forest, Wyoming	4.3 - 5.5	N/A	N/A
North America				
Foster and Glaser 1986	Southeastern Labrador	5.8 - 6.4	1.80 - 5.52	N/A
Foster et al. 1988	Canada	5.3 - 6.4	1.8 - 21.5	2 - 28
Bursik and Moseley 1992	Idaho	5.8	2.0	N/A
Glaser et al. 1990	Minnesota	7 - 7.3	20 - 45	N/A
Glaser 1992	Minnesota	5.6 - 6.1	5.3 - 31.7	N/A
Cooper and Jones 2004	Montana	4.6 - 5.4	N/A	N/A
Cooper and Wolf 2006	California	4.3 - 7.0	1.0 - 35.4	0.2 - 16.7
Europe				
Gorham and Pearsall 1956	Northern England	5.61	3.2	N/A
Wheeler 1980	England and Wales	6.5 - 8.0	>40	N/A
Crowder et al. 1990	Great Britain	3.6 - 7.6	1.2 - 23.1	1.5 - 3.7
Foster and Fritz 1987	Sweden	3.8 - 4.3	0.2 - 0.4	0.1 - 0.4

trifidum, *Halerpestes cymbalaria* ssp. *saximontana*, *Lycopus asper*, *Menyanthes trifoliata*, *Muhlenbergia filiformis*, *Pedicularis groenlandica*, *Spiranthes romanzoffiana*, *Viola macloskeyi* ssp. *pallens*, and a new genus for the Rocky Mountains, *Rynchospora alba*. Mosses include *Aulacomnium palustre*, *Drepanocladus aduncus*, *Sphagnum squarrosum*, *S. terres*, and *Philonotis fontana* (Lemly 2006 personal communication).

The vegetation associated with *Drosera anglica* occurrences elsewhere in North America and Europe are summarized in **Table 3**.

Competitors and relationship to habitat

In peatlands where *Drosera anglica* occurs with *Sphagnum* moss, competition for sunlight can have a significant effect on *D. anglica* size and distribution. The small size of *D. anglica* plants reduces their demand for resources but makes them particularly sensitive to drought and burial by *Sphagnum* growth (Nordbakken et al. 2004). Unlike *D. rotundifolia*, *D. anglica* cannot produce a long axil form to overtop fast-growing *Sphagnum*, and it is therefore outcompeted in dense, tall, moss mats (Crowder et al. 1990).

The ability of *Drosera anglica* to capture and retain insects leads to competition for critical nutrients within occurrences and between carnivorous plants and insect predators. In addition to studies describing the competition within *Drosera* species for limited insect resources (Thum 1986, Gibson 1991), ants have been observed robbing the plants of other insects that were trapped in the leaves.

Variation in microhabitat between the sympatric species of North American *Drosera* species may serve to reduce the interspecific competition for insect prey. A study of two *Drosera* species, *D. rotundifolia* and *D. intermedia*, demonstrated niche partitioning between the two carnivorous plants with respect to prey species captured (Thum 1986). On the slightly elevated hummock microhabitat, *D. rotundifolia* primarily caught *Collembola* (springtails) as prey. In the hollows, *D. intermedia* captured mostly winged insects such as *Diptera* (flies) (Thum 1986).

The prey caught in *Drosera* spp. leaves are often plundered by roaming ants. In one study 61 percent of added flies were taken from *D. rotundifolia* leaves less than 24 hours after addition, before the plant could digest them (Thum 1989b). Ants showed higher activity in the warmer, sunnier, and elevated microhabitat of *D. rotundifolia* compared to the lower, moister habitat of *D. intermedia* and *D. anglica*. Larger plants were better than smaller ones in retaining added flies. The advantage of plundering appears to be more important for the ants than the danger of being caught. The prey collected from *Drosera* plants may be an important source of food for bog-dwelling ants (Thum 1989b).

Herbivores and relationship to habitat

There are few studies of herbivory on *Drosera anglica*, and none specific to Region 2. Caterpillars of a plume moth (*Trichoptilus parvulus*) have been found feeding on an occurrence of *D. capillaris* in Florida, consuming leaf blades, glands, and dead insects trapped by the plant (Eisner and Shepherd 1965). However, it is unlikely that invertebrates specialize in consuming *D. anglica*, as occurrences are localized and productivity of plants and occurrences are low. However, generalist herbivores may opportunistically utilize the plant. Moose on the Kenai Peninsula of Alaska commonly eat *D. rotundifolia* in late May and June when it is in pre-flowering and early flowering stages (LeResche and Davis 1973). Trampling effects due to large herbivores, such as moose, elk, deer or non-native ungulates are likely more significant than the impacts of direct herbivory.

Parasites and disease

An aphid, *Aphis audax* Hille Ris Lambers (likely synonymous with *A. trichoglochinis* Theobald), infests *Drosera anglica* in Scotland (Wood-Baker 1974). Whether this species occurs in Region 2 is unknown. There are no records of disease, but both seeds and seedlings are attacked by fungi in culture (Crowder et al. 1990).

The disjunct nature of the occurrences of *Drosera anglica* within Region 2 and the lack of effective vectors for pathogens suggest that, if present, the effects of pathogens and parasites are small.

Symbiotic and mutualistic interactions

There are no documented examples of symbiotic or mutualistic relationships between *Drosera anglica* and other organisms. The plants are sometimes found covered by filamentous algae, notably *Zygogonum ericetorum* Kutzing, which can provide a good medium for its germinating seeds (Nordbakken et al. 2004).

Table 3. Common vegetation associates for *Drosera anglica* reported from various studies outside USDA Forest Service Region 2.

Reference	Study location	Associated species
North America		
Moseley et al. 1991	Idaho	*Carex lasiocarpa*, *C. livida*, *Menyanthes trifoliata*, *Lycopodium inundatum*, *Eleocharis pauciflora*, *Sphagnum* spp.
Penskar and Higman 1999	Michigan	*Drosera intermedia*, *D. rotundifolia*, *D. linearis*, *Thuja occidentalis*, *Larix laricina*, *Triglochin* spp., *Sarracenia purpurea*, *Tofieldia glutinosa*, *Primula mistassinica*, *Lobelia kalmii*, *Scirpus cespitosus*, *Pogonia ophioglossoides*, *Calopogon tuberosus*, *Sphagnum* spp., *Scorpidium scorpioides*
Glaser et al. 1990	Minnesota	*Scirpus hudsonianus*, *Cladium mariscoides*, *Parnassia palustris*, *Muhlenbergia glomerata*, *Scirpus cespitosus*, *Carex lasiocarpa*, *Drosera rotundifolia*, *D. intermedia*, *Carex livida*, *Utricularia intermedia*
Wheeler 1980	Minnesota	*Carex lasiocarpa*, *C. livida*, *C. limosa*, *C. leptalea*, *Cladium mariscoides*, *Eriophorum angustifolium*, *Menyanthes trifoliata*, *Rhynchospora alba*
Cooper and Jones 2004	Montana	*Carex lasiocarpa*, *Dulichium arundinacea*, *Comarum palustre*, *Menyanthes trifoliata*, *Sphagnum angustifolium*, *S. russowii*, *S. subsecundum*, *S. teres*
Foster and Glaser 1986	Southeastern Labrador	*Carex exilis*, *C. livida*, *Juncus stygius*, *Calliergon stramineum*, *Betula michauxii*, *Menyanthes trifoliata*
Foster and King 1984	Southeastern Labrador	*Cladopidiella fluitans*, *Juncus stygius*
Cooper and Wolf 2006	California	*Carex diandra*, *Carex limosa*, *Carex simulata*, *Drepanocladus sordidus*, *Drosera rotundifolia*, *Eleocharis pauciflora*, *Eriophorum gracile*, *Kalmia polifolia*, *Meesia triquetra*, *Menyanthes trifoliata*, *Rhynchospera alba*, *Scheuchzeria palustris*, *Sphagnum teres*, *Spiranthes romanzoffiana*, *Tofieldia occidentalis*, *Utricularia intermedia*, *Vaccinium uliginosum*
Poulin et al. 1999	Quebec, New Brunswick	*Drosera rotundifolia*, *Eriophorum vaginatum*, *Rubus chamaemorus*, *Scirpus caespitosus*, *Chamaedaphne calyculata*, *Kalmia angustifolia*, *Ledum groenlandicum*, *Oxycoccus macrocarpus*, *Polytrichum strictum*, *Sphagnum fuscum*, *S. magellanicum*, *S. capillifolium*
Europe		
Foster and Fritz 1987	Central Sweden	*Sphagnum tenellum*, *S. balticum*
Crowder et al. 1990b	Great Britain	*Calluna vulgaris*, *Erica tetralix*, *Eriophorum angustifolium*, *E. vaginatum*, *Molinia caerulea*, *Narthecium ossifragum*, *Drosera rotundifolia*
Nordbakken et al. 2004	Southeast Norway	*Sphagnum tenellum*, *S. rubellum*, *Cladopodiella fluitans*
Smart 1982	Northern Scotland	*Sphagnum magellanicum*, *S. papillosum*, *Eleocharis multicaulis*, *Eriophorum angustifolium*, *Narthecium ossifragum*
Wheeler 1980	England and Wales	*Carex dioica*, *C. rostrata*, *Scorpidium scorpioides*, *Drepanocladus lycopodioides*, *Menyanthes trifoliata*, *Mnium psuedopunctatum*
Gorham and Pearsall 1956	Northern England	*Carex panicea*, *C. rostrata*, *Molinia caerulea*, *Eleocharis multicaulis*, *Menyanthes trifoliata*, *Eriophorum angustifolium*, *Sphagnum subsecundum*, *Drosera rotundifolia*, *Utricularia minor*, *Scorpidium scorpioides*
Criodian and Doyle 1997	Ireland	*Eleocharis multicaulis*, *Juncus bulbosa*, *Carex demissa*, *Narthecium ossifragum*, *Myrica gale*, *Scorpidium scorpioides*

CONSERVATION

Threats

The following sections outline the potential threats to the three known *Drosera anglica* occurrences in Region 2 and the peatlands that support them. In addition to direct impacts, a variety of additional factors have affected peatlands, and presumably altered peatland species composition. Some statistics are available on historical rates of wetland loss at national and state levels (Tiner 1984, Dahl 1990); however none of these studies have addressed changes in abundance and distribution of peatland, the wetland type critical for *D. anglica*.

Based on the information the authors reviewed, the three sites are mostly unimpacted, but some present site-specific impacts are noted in their relevant sections.

Hydrologic alteration

Historically, many peatlands within Region 2 were ditched and drained in order to create "productive land" and to increase site suitability for cattle grazing (Cooper et al. 1998, Johnson 2000), but there is no evidence of hydrologic alteration at any of the three sites that support *Drosera anglica*. Direct hydrologic alteration, such as dewatering through ditching, fundamentally changes the ecological properties of impacted wetlands, reducing their suitability for obligate wetland species such as *D. anglica*. Consequently, direct hydrologic alteration represents the single greatest historic and current threat to *D. anglica* occurrences, and protection of water resources in fens is of utmost importance to preserving the viability of the species.

At the same time, since fens are supported in large part by groundwater, a variety of actions outside of their immediate area can alter habitat hydrologic regimes, sediment budgets, or water chemistry, with potentially significant ramifications for wetland dependant species. The water balance of individual basins supporting peatlands varies as a function of precipitation inputs, evaporation and transpiration losses, and the amount of water stored as groundwater (Mitsch and Gosselink 2000). Vegetation in surrounding uplands influences this balance through effects on transpiration and interception of rain or snow (Kauffman et al. 1997). Thus, any natural or anthropogenic process that significantly alters upland vegetation, for example fire or timber harvest, can impact nearby wetlands.

Timber harvest

Changes in basin vegetation cover can alter surface runoff from basins through effects on evapotranspiration rates and snowpack accumulation patterns. Tree canopy removal in a Colorado subalpine watershed increased precipitation reaching the forest floor by approximately 40 percent and increased peak snowpack water equivalent (SWE) by more than 35 percent (Stottlemyer and Troendle 1999, Stottlemyer and Troendle 2001). Logging, whether clearcutting or partial thinning, typically results in increased annual and peak streamflow in logged watersheds (Troendle and King 1987). Although the effects of increased water yield and surface inflows to peatlands are difficult to predict, any changes in fen hydrologic regimes can produce negative effects on fen vegetation.

Increased water yield from upland portions of peatland watersheds could generate wetter conditions, flooding microsites required by *Drosera anglica*. In addition, since fens in the southern Rocky Mountains form only in physically stable locations where stream erosion and sediment deposition are limited, increased sediment yields resulting from upland vegetation removal could increase mineral sediment fluxes to fens, negatively impacting peat formation, nutrient dynamics and water table depths, any of which could affect *D. anglica*.

Most water derived from snowmelt passes through subalpine watersheds not as surface flow, but as subsurface flow where soil processes can significantly alter its chemistry (Stottlemyer and Troendle 1999). As a result, altered snowpack accumulation and melt rates due to changes in upland vegetation cover can affect water chemistry in a variety of ways. For example, Stottlemyer and Troendle (1999) observed significant increases in the average snowpack Ca^{2+}, NO_3^-, and NH_4^+ content, and increased K^+, Ca^{2+}, SO_4^{2-}, NO^{3-}, and HCO^{3-} flux in shallow subsurface flows following logging treatments. The effect of these changes in surface and subsurface flows on peat chemistry and the potential effects on wetland flora are unknown.

Fire

The indirect effects of fire occurring in uplands adjacent to fens supporting *Drosera anglica* occurrences are likely similar to those of mechanical harvest, including increased water and sediment yield and changes in water chemistry. As with logging, the magnitude of these changes relative to pre-fire

conditions should decrease over time, as the density and cover of upland vegetation increases (Troendle and King 1985). Since fire has been a natural component of Rocky Mountain landscapes for millennia (Fall 1997), *D. anglica* is not likely to be strongly influenced by fire patterns that are within the natural range of variability.

A natural fire regime may play an important role in maintaining open fen ecosystems by burning tree and shrub species that may otherwise encroach and shade fens (Matthews 1994, Schnell 2002). Although there are few data available for soil temperature and fire duration mortality thresholds for *Drosera* spp., the genus has been characterized as tolerant of and even opportunistically dependent on low-temperature fires; one species, *D. capillaris*, has even been found colonizing recently burned peat (Brewer 1999).

Since fens typically remain saturated throughout the year, their ability to support fires is low relative to drier upland areas. In addition, fire return intervals characteristic of the subalpine forests surrounding Region 2 fens are relatively long compared to many boreal landscapes (Sherriff et al. 2001), suggesting that fire has had, at most, an episodic role in the population dynamics of the region's *Drosera anglica* occurrences.

Significant departure from historic mean fire return interval could lead to degradation of *Drosera anglica* habitat. A reduction of fire return interval due to more frequent burning could result in an increase in both water and sediment yield within a given watershed, while an increase in fire return interval may reduce water yield and lead to encroachment of woody plants into fens. In addition to these direct impacts on water availability and shading, longer fire return intervals may increase the probability of a high severity fire, which may have exaggerated direct and indirect impacts within a watershed. Since *D. anglica* requires a narrow range of water table depths and is sensitive to shading and burial, any significant change in fire frequency has the potential to influence the suitability of affected wetlands to support *D. anglica*.

Roads and trails

Roads, and to a lesser degree, trail networks, can significantly affect local and watershed-scale hydrologic processes, and can therefore have indirect impacts on fens supporting *Drosera anglica* occurrences. Roads, trails, and their associated engineering structures such as culverts and ditches can alter natural drainage patterns, reduce interception and infiltration rates due to the removal of vegetation and soil compaction, and alter the hydrologic response of basins to both annual snowmelt runoff episodes and isolated convective storm events (Jones 2000, Forman and Sperling 2002). Increased overland flow typically results in a more rapid and extreme hydrologic response to precipitation events, potentially increasing erosion or sediment transport and deposition in affected systems.

Road and trail networks can have a variety of additional effects on wetlands, including the introduction of pollutants and the alteration of water chemistry (e.g. conductivity, cation concentrations, pH) due to road dust, increased sediment deposition, and chemicals used in road maintenance such as dust abatement or deicing agents (Wilcox 1986, Trombulak and Frissell 2000). Since the two Park County, WY occurrences of *Drosera anglica* are fairly remote, the road density in their contributing watersheds is probably relatively low. The La Plata County, CO occurrence is located near a very developed area, and may have a significantly higher road density within its watershed. Therefore, these road network impacts likely represent a minor threat to the Wyoming *D. anglica* occurrences, but may be more significant for the Colorado occurrence; however, there are no data available to support this assessment. However, if road densities increase, introduction of sediment and other foreign material to peatlands could negatively impact *D. anglica*.

Because two of the three Region 2 *Drosera anglica* occurrences are found on floating mats, an environment less likely to be strongly affected by pulses of water or sediment than sites located along fen margins, the effects of altered watershed hydrologic processes (i.e., water yield and sediment transport) due to roads and trails may be modest. More significant perhaps, is the possibility of roads intercepting and diverting spring discharge that feeds into fens. Roads near the Park County, WY 1 and La Plata County, CO occurrences may alter drainage pathways via culverting or ditching, and these potential influences to water distribution must be documented.

The increased disturbance and access resulting from roads and trails can indirectly affect wetlands by promoting the spread of non-native plants (Parendes and Jones 2000) and by providing easier human access (Gelbard and Belnap 2003). Several exotic species are capable of invading wetlands, particularly those that have been altered hydrologically (Wilcox 1995). However, even in disturbed wetlands, weeds have not been observed in the wet and acidic microsites supporting *Drosera anglica* occurrences, suggesting that this specific effect is likely to be minor. Roads

and trails facilitate human access to fens and may increase anthropogenic disturbance and the likelihood of discovery of *D. anglica* occurrences by collectors.

Although off-road use of motor vehicles on USFS land is regulated to prevent damage to vegetation (Code of Federal Regulations, 2006, Section 261.15), impacts to peatlands from off-highway vehicles (OHV's) has occurred. An example is the September 2000 "mudfest" on private land near the Roosevelt National Forest in Colorado, where several hundred OHV's caused severe damage to a fen complex. In addition, OHV use in or near wetlands may contribute pollutants from inefficient combustion and engine emissions (Havlick 2002). Although certainly a factor contributing to the degradation of some fens, there is no evidence to suggest a direct threat to Region 2 *Drosera anglica* occurrences from OHV use. However, sensitive species need to be protected, because even a single OHV could cause significant damage if driven directly onto a *D. anglica* occurrence.

A gated road on the ridge above Park County, WY 1 runs through a meadow adjacent to the fen (Heidel and Laursen 2003). Although this road is closed to public access, it has the potential to increase visitation and commensurate impacts to the *Drosera anglica* occurrence at Park County, WY 1.

Peat extraction

Because of its high porosity and water holding capacity, peat has a variety of horticultural and agricultural applications, including use as a lawn and garden soil amendment and for turf maintenance on golf courses. Industrial applications include use as a filtration medium for waste-water and sewage effluents and, in its dehydrated form, as an absorbent for fuel and oil spills on both land and water (WEC 2004).

Sites possessing the necessary hydrologic conditions for peat accumulation are rare in Region 2 because of its relatively dry climate (Chimner and Cooper 2003). Indeed, with the exception of the northern Great Lakes region and portions of the northeastern United States and the Atlantic seaboard, peatlands form only a small component of the total land cover nationally. Not surprisingly then, peat production in the United States is small relative to global production. In 2002, for instance, the United States produced 642 metric tons of peat, less than 3 percent of world peat production (DiFrancesco and Jasinski 2004).

In Colorado, there are currently three active peat-mining claims, which cover a total of 47.7 hectares of land, and 17 inactive claims. None of these 20 claims is within La Plata County, where a *Drosera anglica* occurrence was recently discovered (Colorado Division of Minerals and Geology 2006). No information was found regarding peat mining in Wyoming.

The large energy output of peat has made it an attractive source of energy, at least locally in areas supporting large peatlands. However, interest in the United States in developing peat resources for energy purposes has diminished since its peak in the 1970's, due in part to the relatively low price of natural gas and oil, and the development of environmental regulations protecting wetlands. Although no reliable statistics are available, peat production for agricultural, horticultural, and energy uses in Region 2 is likely small due to the availability of inexpensive imports from outside of the region (primarily Canada) and various regulations limiting peatland development. Consequently, peat mining currently appears to represent a minor threat to known *Drosera anglica* occurrences in Region 2. If peat mining were to resume, however, it would present a major impact to *D. anglica* habitat.

Mineral development

Mineral extraction activities, including hard rock mining, and oil and natural gas extraction, do not appear to pose an imminent threat to *Drosera anglica* occurrences. However, if commenced within the watershed of either of the *D. anglica* occurrences, mining may pose a threat to the quality of water entering the fens. Mining often exposes pyrite rich rock that oxidizes in water to form sulfuric acid (known as acid mine drainage), which could significantly alter the water chemistry at the sites.

Livestock and native ungulate grazing

The effect of livestock grazing on *Drosera anglica*, at both the individual and occurrence levels, is largely unknown. *Drosera anglica* has been shown to positively respond to some forms of disturbance, likely due to its high light requirements and relatively poor competitive ability. For example, a mowing treatment in a Belgian rich fen, designed to simulate the effects of early-season grazing, resulted in a significant increase in the frequency of *D. rotundifolia* (Vyvey 1992). Since the floating mat environments characteristic of Region 2 *D. anglica* occurrences are perennially wet,

livestock may avoid using them. However, even modest livestock use can punch holes through the floating mat, destroying the root and rhizome systems of plants that form the floating mat. Since floating mat plants are all slow growing, disturbed peat will be exposed to oxygen for a long period of time, resulting in peat loss.

Some livestock use has been noted at and near the Park County, WY 1 site. Some trampling was noted in the original sensitive plant survey (Heidel and Laursen 2003a). Native ungulates, including elk and moose, can also significantly affect wetlands, possibly impacting *Drosera anglica* occurrences.

Recreational impacts

Recreational impacts to fens are typically due to trampling. Users including fisherman, native plant enthusiasts, and hikers often come to the edge of floating mats to fish and to enjoy the open views, reflections, and unusual colors.

The La Plata County, CO site is not far from a major ski area and highway. Large wastewater ponds, utility lines, and recreational trails are close by. Currently the biggest impact observed at the site are the trampled paths made by curious botanists. At least three parties had visited the site and left obvious tracks since the occurrence was found. That impact will likely fade when the snows come and next year's sedges grow (Lemly 2006 personal communication). However, given the intense development in the immediate area, the easy access to the site, and the interest generated by a newly discovered occurrence of a carnivorous plant, it is reasonable to expect that recreational impact at this site will increase in the future.

There are no documented impacts on *Drosera anglica* occurrences from winter recreation such as cross-county skiing, snowshoeing, or snowmobiling. However, compaction of accumulated snow from winter recreation has the potential to impact the species by causing later spring melt and altered peat temperatures, effectively reducing the length of the growing season for plants (Cooper unpublished data). Winter recreation, snowmobiling in particular, has been identified as a potential threat to *D. rotundifolia* occurrences on the Routt (Proctor 2004 personal communication) and Arapaho national forests (Popovich 2004 personal communication).

Over-collection

Human use of *Drosera* species for medicinal purposes has a long and interesting history. The 'perpetual dew' of sundews has been valued as an herbal remedy for a wide variety of ailments. Accounts from as early as the 16th century document the use of *Drosera*-based tinctures to treat such varied maladies as "consumption, swooning, and faintness of harte" (William Turner 1568, cited in Juniper et al. 1989). Additional historical accounts describe its use as an aphrodisiac and as a remedy for complaints of old age, arteriosclerosis, corns and warts, whooping cough, and small pox (Juniper et al. 1989). Modern herbalists prescribe *Drosera* species as a diuretic, a laxative, and as a treatment for a variety of kidney, stomach, and liver problems. The potential value of *D. anglica* as an herbal remedy may create an incentive for collection, particularly as commercial markets exist for *Drosera* tinctures and compounds. Although no documented occurrences of collections for this purpose are known from Region 2, the limited distribution and abundance of *D. anglica* suggest that collection could represent a serious threat.

In addition to their use as herbal remedies, *Drosera* species have long held the interest of botanists and horticulturists because of their unique biology and carnivorous habit. There is an active trade in carnivorous plant species, and several organizations such as the International Carnivorous Plant Society exist to support the culture of carnivorous plants. Through advocacy and support for research and conservation, carnivorous plant enthusiasts clearly benefit the species they love. However, it is conceivable that individuals could collect wild occurrences, with serious negative consequences. Each of the known occurrences of *D. anglica* could be over-collected in a single harvest visit. Trailing by interested humans within the fen containing the newly discovered Colorado population was noted during a botanical visit to the site, but the impact was assessed as temporary (Lemly 2006 personal communication).

In response to the threat posed by over-collection of sensitive plants, the Montana State Legislature and Regions 1 and 4 of the USFS adopted a collection moratorium on six medicinally popular plants, including all species of *Drosera* (USDA Forest Service 1999).

Exotic species

Although exotic species are generally recognized as one of the principal threats to the integrity of ecological systems (Mack et al. 2000, Crooks 2002), there is no evidence to suggest that *Drosera anglica* is directly threatened by exotic species within Region 2. None of the state or county-listed noxious weed species listed in Wyoming is noted in habitat descriptions of known occurrences. Although exotics such as Canada thistle (*Cirsium arvense*) may invade fens, this is typically associated with hydrologic alterations such as ditching. In addition, the floating mat environments supporting Region 2 *D. anglica* occurrences do not appear conducive to weed invasion.

Atmospheric deposition of pollutants

In nutrient-poor environments, *Drosera anglica* may have a competitive advantage over co-occurring species due to its ability to assimilate nitrogen from invertebrates (Thum 1986, Stewart and Nilsen 1992, Nordbakken et al. 2004). As a consequence, *D. anglica* may be vulnerable to the increased deposition of airborne nitrogen observed in portions of Region 2 (Svensson 1995). A wide variety of ecological responses has been shown to result from nitrogen deposition, but no studies have focused on fens specifically. Although large areas of land are exposed to low levels of atmospheric nitrogen deposition, hotspots of elevated nitrogen deposition occur downwind of large metropolitan centers or significant agricultural operations (Fenn et al. 2003). Consequently, nitrate concentrations in surface waters west of the Continental Divide have generally been found to be lower than surface waters to the east (Burns 2004).

Climate change

Given the role of climate as a primary control on the majority of hydrogeomorphic, biogeochemical, and ecological processes, large-scale climatic shifts, whether due to natural or anthropogenic forces, may profoundly affect the structure and function of the wetlands supporting *Drosera anglica*. Potential changes include altered plant community composition and productivity, changes in disturbance regimes, and modification of key hydrologic variables (Hogenbirk and Wein 1991, Naiman and Turner 2000, Brinson and Malvarez 2002, Moore 2002, Poff et al. 2002). Both positive and negative feedbacks are possible, complicating predictions of individual species or community and ecosystem responses (Weltzin et al. 2000).

Because of their strong dependence on watershed-scale hydrologic processes, wetlands, and fens in particular, may be especially sensitive to major shifts in either temperature or precipitation. The sensitivity of *Drosera anglica* to desiccation suggests that the warmer regional temperatures predicted under some global climate change scenarios (U.S. Environmental Protection Agency 1998) may adversely affect the species. Increased precipitation, called for by some models, may offset the negative hydrologic effects of warmer temperatures, but still have a negative effect on the viability of *D. anglica* occurrences by shifting the delicate balance between *D. anglica* and its competitors (Nordbakken et al. 2004). For instance, Moore (2002) found that production of graminoids and herbaceous dicots increased in response to rising water table elevation; this higher productivity could result in higher competition between *D. anglica* and associated vegetation.

Ultimately, the most important climatic factor influencing the future of peatlands in Region 2 is likely to be the spatial and temporal patterns of future precipitation (Moore 2002). Because of the regional climate, areas capable of accumulating peat are rare on the landscape, and rates of peat formation are exceedingly slow (Chimner et al. 2002, Chimner and Cooper 2003). The disjunct nature of Region 2 *Drosera anglica* occurrences, widely separated from other occurrences and suitable habitats, suggests that the fate of the species in Region 2 is intimately tied to that of the wetlands presently supporting them – the conclusion reached for other rare fen species.

Conservation Status of Drosera anglica in Region 2

USFS Region 2 has designated *Drosera anglica* a sensitive species principally because of its rarity and the sensitivity of its habitat to alteration. However, there are insufficient data available to make conclusive statements regarding trends in the abundance of *D. anglica* within Region 2. Because occurrences are so small and isolated, periodic drought during the Holocene may have led to local extirpation of occurrences in areas in Region 2 where *D. anglica* does not now occur. Extirpation could also occur as a natural byproduct of successional changes associated with terrestrialization of basin fens. As ponds with floating mat fens gradually fill in with organic and mineral sediment, the floating mat can become a solid peat body dominated by tall *Carex* spp. that can outcompete *D. anglica*.

There is still uncertainty as to the specific origin of Region 2 *Drosera anglica* occurrences. However, the global distribution for *D. anglica* mirrors that of many other subalpine and alpine species in the southern Rocky Mountains, suggesting a similar biogeographic origin (Cooper et al. 2002, Weber 2003). Weber (2003) argued that the contemporary high mountain flora has been in place since Tertiary times, and that it predates the modern boreal floras. His argument, based on the distributions of a variety of vascular and cryptogamic species, is contrary to the generally accepted concept articulated by Axlerod and Raven (1985), which suggests that many disjunct subalpine and alpine species in the region originated by migration from northern sources during major glacial periods or from the upward migration of pre-adapted lowland taxa.

Instead, Weber (2003) suggests, "the major mountain masses of the Northern Hemisphere have been populated by modern species of plants dating from the Tertiary, these mountain masses were formerly sufficiently well-connected, possibly over larger land connections across what is now the arctic region, to permit large areas for many species, and that present endemism has come about through restrictions of the formerly extensive ranges." Although Weber's discussion does not specifically address *Drosera anglica*, this species' distribution is similar to many of the examples he does cite. If correct, his hypothesis indicates that *D. anglica* has been present in the region for far longer than suggested by earlier biogeographic theories.

Regardless of origin, the small number and highly disjunct nature of Region 2 occurrences, the fens supporting them, and the limited dispersal distances that are likely typical for *Drosera* species, suggest that existing occurrences require protection and no new occurrences are likely to form. Though diminutive, *D. anglica* are distinctive plants, not likely to be overlooked or misidentified in botanical surveys, as is common for many *Carex* species and bryophytes. However, since fens, and especially floating mats, can be difficult to access, no systematic survey of Region 2 fens has been conducted, and it is certainly possible that additional undocumented occurrences could be found. As a consequence, it is recommended that all fens be carefully evaluated for the presence of *D. anglica* prior to significant shifts in management.

The primary functional elements of the habitat supporting *Drosera anglica* that need to be conserved in order to ensure the persistence of the species are the hydrologic regime, the integrity of the peat body, and the lack of mineral sediment or nutrient deposition. Since the hydrologic regime represents the single greatest influence on fen ecology, actions with the potential to alter water and sediment flux into fens, such as trail cutting, road building, timber harvesting, prescribed fire, or water diversions, need to be critically evaluated early in project planning, and effects should be monitored following implementation.

Relatively long-term, stable hydrologic processes support fens and the plants that grow in them, including *Drosera anglica*. This hydrologic stability leads to stable rates of primary production and decomposition, and the net results are accumulations of peat. Because peat accumulation rates in the Rocky Mountains are approximately 20 cm per millennium (Chimner et al. 2002, Ford et al. 2002), the presence of significant peat bodies indicates relatively constant physical and hydrologic conditions over thousands of years. This suggests that fens supporting Region 2 *D. anglica* occurrences may be relatively resilient to small to intermediate disturbances in the surrounding landscape.

However, activities within fens that disrupt microsite stability can have serious impacts on localized *Drosera anglica* occurrences. Although these impacts may not jeopardize the long-term functioning of the fen as a whole, given such slow rates of peat accumulation, the direct, local impacts may be a significant source of mortality within the *D. anglica* occurrence.

The physical characteristics of the peat body help to maintain the necessary range of capillarity, bulk density, and water holding capacity to produce the edaphic, hydrologic, and geochemical conditions necessary for peatland vegetation such as *Drosera anglica*. Even small amounts of mineral sediment deposition within a fen can exceed the slow rate of peat accumulation and rapidly change the physical character of the peat body. Given the slow rates of peat accumulation, a single significant sedimentation event could affect surface vegetation for centuries.

Likewise, small inputs of nutrients, especially nitrogen, from aerial deposition or livestock excrement, can dramatically change the nutrient balance in the characteristically nutrient-poor peatland habitats that support *Drosera anglica*. Any significant fertilizing effect from a nutrient source would favor more generalist competitors over the carnivorous fen specialist, *D. anglica*.

Management of Drosera anglica in Region 2

Implications and potential conservation elements

First and foremost, maintaining the integrity of the fens supporting Region 2 *Drosera anglica* occurrences is essential to ensuring the long-term survival of the species in the region. Specifically, this includes minimizing anthropogenic impacts to hydrologic, sediment, and disturbance regimes resulting from management actions. Since fens in the region and their sensitivity to anthropogenic impacts are generally poorly understood, basic hydrologic and vegetation data need to be collected prior to, during, and following any significant change in management.

Since perennial groundwater inflow is the critical driver of the hydrologic and geochemical processes leading to peat formation, maintaining the hydrologic integrity of basins surrounding fens supporting *Drosera anglica* occurrences is critical. Since Region 2 occurrences of *D. anglica* are so isolated from one another, the potential for replenishment of these unique occurrences, if lost, is exceedingly low.

In addition, management actions resulting in physical trampling of peatlands supporting *Drosera anglica* must be avoided. The potential long-term trend towards greater native ungulate use at the site may also threaten the integrity of floating mats supporting *D. anglica*. Although the relative importance of human foot traffic, ungulate use, and interannual climate variation is not known, foot and hoof prints can significantly affect fen species.

Tools and practices

Frequent field checking of *Drosera anglica* occurrences is important to the conservation of the species as knowledge of its distribution and abundance is critical to management decisions and monitoring efforts. Identification of potential habitat is also fundamentally important since it may reveal previously unknown occurrences as well as define the areas where extirpated occurrences may have existed. An important conservation tool available to the USFS is the continued listing of *D. anglica* as a sensitive species. Designation of the fens that support *D. anglica* in Region 2 as Research Natural Areas, Botanical Special Interest Areas, or other special areas may help to initiate necessary information gathering efforts. In addition, these designations may confer land use and activity restrictions that could be beneficial to the long-term viability of the species.

Applying management tools to known impacts on the hydrology, peat body integrity, or sediment and nutrient balance at fens supporting *Drosera anglica* may both improve the conditions of the occurrences and provide the opportunity for monitoring the response of the species to changes in human activity. Closing, rerouting, or regulating use of roads and trails that provide easy access to the *D. anglica* occurrences at present may help to reduce damage from trampling and collecting. For example, an analysis of visitor use of the gated road as an access route to the Park County, WY 2 occurrence may provide guidance for the management of that road.

Placement of signs at occurrences that instruct visitors about the detrimental effects to fens and vegetation may reduce careless trampling, or it may draw the attention of collectors to the site. Terminating grazing permits or fencing off livestock access to fens with *Drosera anglica* may reduce both physical impacts to the peat body and nutrient additions from excrement. Acquiring all water rights for the water sources of the fens that support *D. anglica* would ensure that the USFS regulates all relevant water diversions.

An evaluation of forest harvesting, mining, road maintenance, water diversion, and other land management activities within the watersheds containing *Drosera anglica* occurrences may offer other insights into opportunities to monitor the response of the species to changes in activity level. Implementation of these management tools may generate valuable information and are likely to benefit *D. anglica* and the fen habitats that support it.

Availability of reliable restoration methods

There are few studies of fen restoration in the Rocky Mountain Region. However, the limited research that has been conducted suggests that restoration of fen vegetation is contingent upon effective restoration of wetland hydrology (Cooper et al. 1998, Cooper and MacDonald 1999). Typically, this requires removing obstacles or diversions in the groundwater flow systems that support fens. Propagation of plant material for transplanting is often a necessary component of restoration and can be difficult for fen species that are highly adapted to specific nutrient and hydrologic conditions. A study from Finland (Galambosi et al.

2000) describes a technique for cultivating *Drosera anglica* with the goal of maximizing production of secondary metabolites.

Information Needs and Research Priorities

All *Drosera anglica* occurrences in Region 2 were discovered within the past few decades, demonstrating the importance of surveying fen habitats for this species. Based on distributional similarities to other subalpine and alpine floristic elements in the region, it is likely that the species was at one time more widely distributed than it is at present. Consequently, there may be yet more occurrences awaiting discovery. A broad regional inventory of fens would be of great value in increasing the understanding of the distribution and conservation status of *D. anglica*. Since fens support a large number of rare species in addition to *D. anglica*, such a broad-scale effort would also significantly benefit the overall understanding of biodiversity in the region (Heidel and Laursen 2003a, Heidel and Laursen 2003b).

Remote sensing data, such as color infrared aerial photographs, in conjunction with existing land cover and vegetation data sets available on many national forests, could be used to identify potential habitat. Remotely sensed products, such as high resolution hyperspectral imagery, offer additional powerful means of identifying wetlands, and they could be useful for stratifying wetlands on the basis of their hydrology and vegetation. The floating mats characteristic of two of the three Region 2 *Drosera anglica* occurrences exhibit distinct spectral signatures and could be readily identified for field inventory.

Since most existing records lack data regarding occurrence size, comprehensive demographic surveys of known occurrences need to be conducted in order to better evaluate the status of *Drosera anglica* occurrences and to provide baseline data critical for future monitoring efforts. Known occurrences must be periodically revisited in order to identify potential population trends.

A variety of methods could be used in surveying efforts. Although qualitative methods such as photopoints can provide useful indicators of broad changes to habitat (e.g. major drying or flooding of wetlands, woody plant encroachment, etc.), quantitative methods of estimating occurrences are far more reliable for developing initial occurrence size estimates and for estimating population trends. Although *Drosera anglica* is easily identified anytime during the growing season, monitoring visits timed to coincide with flowering (late June to July) and fruiting (July to August) would provide additional information important for population modeling.

It is also of critical importance that more environmental data be collected for fens supporting Region 2 occurrences. Of particular importance is hydrologic and geochemical characterization of sites supporting known *Drosera anglica* occurrences. Wetland hydrologic regime is the principal variable governing the functioning of fens and their dependent flora. More data are needed to characterize seasonal and annual water table fluctuations in relation to surface and groundwater inputs and climatic fluctuations. A more thorough and comprehensive understanding of the hydrogeologic setting of fens supporting *D. anglica* occurrences is also important, as this would provide key information needed to assess how management activities carried out in the broader watershed may affect fen hydrology and water chemistry.

Because of the small number of Region 2 occurrences and their disjunct distribution, issues of genetic integrity need to be addressed by future research and in the development of any conservation strategies. Each of the fens supporting Region 2 occurrences has a unique developmental history driven in large part by its specific hydrogeochemical and climatic setting. It is possible that individual occurrences may contain unique alleles, and occurrence extirpation might result in the loss of important genetic diversity.

Because of the large importance of physical drivers on wetland function, personnel knowledgeable about wetland hydrology are an essential part of teams evaluating the implications of different management activities on fens. Their input, along with that of a botanist or plant ecologist, is critical in developing meaningful ecological models, identifying targets and threats, and developing management and monitoring plans. The effects of management need to be evaluated in relation to key ecological factors, and these factors must be assessed at multiple spatial scales.

Definitions

Adaxial – nearest to or facing toward the axis of an organ or organism; "the upper side of a leaf is known as the adaxial surface" [syn: ventral] [ant: abaxial].

Adventitious – of or belonging to a structure that develops in an unusual place: *adventitious roots.*

Allochthonous – originating from outside the system, not formed on-site.

Androecium – the stamens of a flower considered as a group.

Anther – pollen-bearing structure part of stamen.

Axillary – located in an axil (the upper angle between the stem and a lateral organ, such as a leaf).

Bog – an ombrotrophic peatland, i.e. one deriving water and nutrients solely from precipitation; typically acidic and dominated by *Sphagnum* mosses.

Capillary fringe – that zone of soil immediately above the water table that acts like a sponge, sucking water up from the underlying water table and retaining this water somewhat tenaciously; soil pores act like capillary tubes.

Chasmogamous – of, or relating to, a flower that opens to allow for pollination.

Corolla – portion of flower comprised of petals.

Cymose – having a usually flat-topped flower cluster in which the main and branch stems each end in a flower that opens before those below it or to its side.

Dehiscent – the spontaneous opening at maturity of a plant structure, such as a fruit, anther, or sporangium, to release its contents.

Diploid – containing a paired set of chromosomes.

Dormancy – a period of growth inactivity in plants observed even when suitable environmental conditions for growth are present.

Endangered – a species, subspecies, or variety likely to become extinct in the foreseeable future throughout all of its range or extirpated in a significant portion of its range.

Entire – having a margin that lacks any serrations.

Extrorse – facing outward.

Fen – a peatland whose primary water source is groundwater.

Fugacious – withering or dropping off early.

G1 ranking – NatureServe Global Conservation Status Rank—Critically imperiled globally because of extreme rarity (five or fewer occurrences or very few remaining individuals) or because of some factor making it especially vulnerable to extinction (NatureServe 2006).

G2 ranking – NatureServe Global Conservation Status Rank—Imperiled globally because of rarity (6 to 20 occurrences) or because of factors demonstrably making a species vulnerable to extinction (NatureServe 2006).

G3 ranking – NatureServe Global Conservation Status Rank—Vulnerable throughout its range or found locally in a restricted range (21 to 100 occurrences) or because of other factors making it vulnerable to extinction (NatureServe 2006).

G4 ranking – NatureServe Global Conservation Status Rank—Apparently secure, though it may be quite rare in parts of its range, especially at the periphery (NatureServe 2006).

G5 ranking – NatureServe Global Conservation Status Rank—Demonstrably secure, though it may be quite rare in parts of its range, especially at the periphery.

Glabrous – lacking hairs, trichomes, or glands, i.e. smooth.

Gynoecium – the female reproductive organs of a flower; the pistil or pistils considered as a group.

Herbaceous – plant lacking an above ground persistent woody stem.

Holarctic – of, relating to, or being the zoogeographic region that includes the northern areas of the earth and is divided into Nearctic and Palearctic regions.

Hybridization – the result of a genetic cross between two species.

Hypocotyl – the part of the axis of a plant embryo or seedling plant that is below the cotyledons.

Hyponasty – an upward bending of leaves or other plant parts, resulting from growth of the lower side.

Karyotype – the characterization of the chromosomal complement of an individual or a species, including number, form, and size of the chromosomes.

Kettle pond – a small, often round, water-filled depression formed when a piece of glacial ice breaks away from the edge of a retreating glacier, and becomes partially buried under sediment deposited by the glacier; when the fragment of ice melts, the overlying sediment settles down and forms a depression that often fills with water.

Lectotype – a specimen chosen by a later researcher to serve as the primary type; it is chosen from among the specimens available to the original author of a name when the holotype was either lost or destroyed, or when no holotype was designated.

Loculicidally – ("Loculicidal") longitudinally dehiscent along the capsule wall between the partitions of the locule, as in the fruits of irises and lilies.

Mycorrhiza – a fungus that can form a symbiotic association with the root of a higher plant.

Obovate – egg-shaped, with the narrower end near the point of attachment.

Obtuse – blunt, with sides coming together at an angle greater than 90 degrees.

Oligotrophic – lacking in plant nutrients and having a large amount of dissolved oxygen throughout; used of a pond or lake.

Ombrogenous – having rain as its only source of water.

Ombrotrophic – term referring to wetlands hydrologically supported by precipitation alone.

Peatland – any one of several different wetland types that accumulates partially decomposed organic matter (peat).

Poor Fen – weakly minerotrophic, acidic peatland with pH ranging from 3.8-5.7.

Pistil – the seed-producing organ of a flower, consisting of a stigma, style, and ovary.

Pollen – the male spores in an anther.

Population Viability Analysis – an evaluation to determine the minimum number of plants needed to perpetuate a species into the future, the factors that affect that number, and current population trends for the species being evaluated.

Propagule – unit capable of creating a new individual. Can be sexual (e.g. seed), or asexual/vegetative.

Pubescent – bearing hairs.

Recruitment – the addition of new individuals to a size or age class.

Rosette – radial arrangement of leaves, typically originating at a basal position.

S1 ranking – NatureServe Subnational Conservation Status Rank—Critically imperiled in the state or province because of extreme rarity (five or fewer occurrences or very few remaining individuals) or because of some factor making it especially vulnerable to extinction (NatureServe 2006).

S2 ranking – NatureServe Subnational Conservation Status Rank—Imperiled in the state or province because of rarity (6 to 20 occurrences) or because of factors demonstrably making a species vulnerable to extinction (NatureServe 2006).

S3 ranking – NatureServe Subnational Conservation Status Rank—Vulnerable in the state or province due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation (NatureServe 2006).

S4 ranking – NatureServe Subnational Conservation Status Rank—Apparently secure, uncommon in the state or province but not rare; some cause for long-term concern due to declines or other factors (NatureServe 2006).

S5 ranking – NatureServe Subnational Conservation Status Rank—Demonstrably secure, common, widespread and abundant in the state or province (NatureServe 2006).

S#S# ranking – NatureServe Subnational Conservation Status Rank—Range Rank—A numeric range rank (e.g., S2S3) is used to indicate the range of uncertainty about the status of the species or community; ranges cannot skip more than one rank (e.g., SU should be used rather than S1S4) (NatureServe 2006).

Scape – erect leafless flower stalk growing directly from the ground as in a tulip [syn: flower stalk].

Sigmoid-fusiform – doubly curved, like the letter S, and tapering at each end (spindle–shaped).

Spatulate – spoon-shaped.

Stamen – pollen-producing organ of a flower.

Style – stalk-like portion that connects ovary to stigma in many pistils.

Superoxides – highly reactive compounds produced when oxygen is reduced by a single electron; in biological systems, they may be generated during the normal catalytic function of a number of enzymes and during the oxidation of hemoglobin to methemoglobin; in living organisms, superoxide dismutase protects the cell from the deleterious effects of superoxide.

Talus – accumulation of coarse rock debris, often at base of cliff or steep slope.

Tentacular – of, relating to, or resembling tentacles.

Testa – the often thick or hard outer coat of a seed.

Threatened – defined in the Endangered Species Act as a species, subspecies, or variety in danger of becoming endangered within the foreseeable future throughout all or a significant portion of its range.

Tufa – the calcareous and siliceous rock deposits of springs, lakes, or ground water.

References

Abrams, L. 1944. Illustrated flora of the Pacific states. Stanford University Press, Stanford, CA.

Andrus, R.E. 1986. Some aspects of *Sphagnum* ecology. Canadian Journal of Botany 64:416-426.

Associated Press. 1999 Mar 30. Monsanto's new weapon against crop pests. AP1/118/S 02:13Z.

Axelrod, D.I. and P.H. Raven. 1985. Origins of the Cordilleran flora. Journal of Biogeography 12:2147.

Baskin, C., P. Milberg, L. Andersson, and J. Baskin. 2001. Seed dormancy-breaking and germination requirements of *Drosera anglica*, an insectivorous species of the Northern Hemisphere. Acta Oecologica 22:1-8.

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

Bekesiova, I., J.P. Nap, and L. Mlynarova. 1999. Isolation of high quality DNA and RNA from leaves of the carnivorous plant *Drosera rotundifolia*. Plant Molecular Biology Reporter 17:269-277.

Brewer, J.S. 1999. Effects of fire, competition and soil disturbances on regeneration of a carnivorous plant (*Drosera capillaris*). American Midland Naturalist 141:28-42.

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

Bureau of Land Management. 2000. Colorado BLM State Director's Sensitive Species List (Animals and Plants). Available online at: http://www.co.blm.gov/botany/sens_species.htm.

Bureau of Land Management. 2002. Sensitive Species Policy and List. Bureau of Land Management, Cheyenne, WY. Available online at: http://www.wy.blm.gov/wildlife/02species.pdf.

Burns, D.A. 2004. The effects of atmospheric nitrogen depositions in the Rocky Mountains of Colorado and southern Wyoming, USA – a critical review. Environmental Pollution 127:257-269.

Bursik, R.J. and R.K. Moseley. 1992. Vegetation and water chemistry monitoring and twenty-year floristic changes at Huff Lake Fen, Kanisksu National Forest. Idaho Game and Fish Department, Boise, ID.

Cambell, D.R. and L. Rochefort. 2003. Germination and seedling growth of bog plants in relation to the recolonization of milled peatlands. Plant Ecology 169:71-84.

Cameron, K.M., K.J. Wurdack, and R.W. Jobson. 2002. Molecular evidence for the common origin of snap-traps among carnivorous plants. American Journal of Botany 89:1503-1509.

Chanda, S. 1965. The pollen morphology of Droseraceae with specific reference to taxonomy. Pollen Et Spores 7: 509-528.

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

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

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

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

Code of Federal Regulations. 2006. Prohibitions for the Forest Service, Department of Agriculture. Title 36, volume 2, chapter 2, section 261. Available online at: http://www.access.gpo.gov/nara/cfr/waisidx_06/36cfr261_06.html.

Cohu, C. 2003. Population genetic analysis of Colorado's *Drosera rotundifolia* using allozyme electrophoresis. Thesis. Western State College, Gunnison, CO.

Colorado Natural Heritage Program. 2004. Tracked vascular plant species. Available online at: http://www.cnhp.colostate.edu/tracking/vascular.html.

Cooper, A., T.P. McCann, and B. Hamill. 2001. Vegetation regeneration on blanket mire after mechanized peat-cutting. Global Ecology and Biogeography 10:275-289.

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

Cooper, D.J. 1991. The habitats of 3 boreal fen mosses new to the southern Rocky Mountains of Colorado. Bryologist 94:49-50.

Cooper, D.J. 1996. Water and soil chemistry, floristics, and phytosociology of the extreme rich High Creek Fen, in South Park, Colorado, USA. Canadian Journal of Botany 74:1801-1811.

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

Cooper, D.J. and J.S. Sanderson. 1997. A montane *Kobresia myosuroides* fen community type in the Southern Rocky Mountains of Colorado. Arctic and Alpine Research 29:300-303.

Cooper, D.J. and E.C. Wolf. 2006. Fens of the Sierra Nevada, California. Report prepared for the USDA Forest Service, Region 5, Vallejo, CA.

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

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

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

Criodian, C.O. and G.J. Doyle. 1997. *Schoenetum nigricantis*, the *Schoenus* fen and flush vegetation of Ireland. Biology and Environment: Proceedings of the Royal Irish Academy 97B:203-218.

Cronquist, A. 1981. An integrated system of classification of flowering plants. The New York Botanical Garden, Bronx, NY.

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

Crowder, A.A., M.C Pearson, P.J. Grubb, and P.H. Langlois. 1990. Biological flora of the British Isles. No. 167. *Drosera* L. Journal of Ecology 78:233-267.

Cruden, R. 1977. Pollen-ovule ratios: a conservative indicator of breeding systems in flowering plants. Evolution 31: 32-46.

Crum, H.A. 1988. A focus on peatlands and peat mosses. University of Michigan Press, Ann Arbor, MI.

Dahl, T.E. 1990. Wetlands losses in the United States, 1780's to 1980's. USDI Fish and Wildlife Service, Washington, D.C.

Damman, A.W.H. 1986. Hydrology, development, and biogeochemistry of ombrogenous peat bogs with special reference to nutrient relocation in a western Newfoundland bog. Canadian Journal of Botany 64:384-394.

Darwin, C. 1875. Insectivorous plants. Appleton and Co., New York, NY.

Darwin, F. 1878. Experiments on the nutrition of *Drosera rotundifolia*. Journal of the Linnean Society. Botany 17: 17-32.

DiFrancesco, C.A. and S.M. Jasinski. 2004. Historical Statistics for Mineral and Material Commodities in the United States - Peat, U.S.G.S. Open-File Report 01-006. USDI Geological Survey. Available online at: http://minerals.usgs.gov/minerals/pubs/of01-006/.

Eisner, T. and J. Shepherd. 1965. Caterpillar feeding on a sundew plant. Science 150:1608-1609.

Ellison, A.M. and N.J. Gotelli. 2001. Evolutionary ecology of carnivorous plants. Trends in Ecology & Evolution 16: 623-629.

Engelhardt, T.L. 1998. Pollination ecology of the round-leaved sundew, *Drosera rotundifolia* L. (Droseraceae) in Sequoia National Park, California. PhD dissertation. California State University, Fullerton, CA.

Erdtman, G., J. Praglowski, and S. Nilsson. 1963. An introduction to a Scandinavian pollen flora. Almqvist and Wiksells, Stockholm, Sweden.

Erman, D.C. and N.A. Erman. 1975. Macroinvertebrate composition and production in some Sierra Nevada minerotrophic peatlands. Ecology 56:591-603.

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

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

Fertig, W. 1997. Plant species of special concern on Shoshone National Forest: 1996 survey results. Unpublished report prepared by the Wyoming Natural Diversity Database. Laramie, WY.

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

Ford, R.L., M. Matyjasik, and N. Keate. 2002. Geomorphic setting, classification, and peat-accumulation rates of selected wetlands in the Uinta Mountains, Utah. Proceedings from a meeting of the Geological Society of America, 28 Oct 2002, Denver, CO. Available online at: http://gsa.confex.com/gsa/2002AM/finalprogram/abstract_46521.htm.

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

Foster, D.R. and S.C. Fritz. 1987. Mire development, pool formation and landscape processes on patterned fens in Dalarna, Central Sweden. The Journal of Ecology 75:409-437.

Foster, D.R. and P.H. Glaser. 1986. The raised bogs of south-eastern Labrador, Canada: classification, distribution, vegetation and recent dynamics. The Journal of Ecology 74:47-71.

Foster, D.R. and G.A. King. 1984. Landscape features, vegetation, and developmental history of a patterned fen in southeastern Labrador, Canada. Journal of Ecology 72:115-143.

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

Galambosi, B., Z. Galambosi, and M. Repcak. 2000. Growth, yield and secondary metabolite production of *Drosera* species cultivated in peat beds in Finland. Suo 51:47-57.

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

Gervais C. and R. Gauthie. 1999. Cytotaxonomical study of the species and natural hybrids of genus *Drosera* (Droseraceae) in Quebec. Acta Botanica Gallica 146:387-401.

Gessner, M.L. 1998. Letter on Regional Policy on the Protection of Fens. U.S. Fish and Wildlife Service. Regional Director, Region 6.

Gibson, T.C. 1991. Competition among threadleaf sundews for limited insect resources. So American Naturalist 138: 785-789.

Givnish, T.J., E.L. Burkhardt, R.E. Happel, and J.D. Weintraub. 1984. Carnivory in the Bromeliad Brocchinia-Reducta, With a Cost-Benefit Model for the General Restriction of Carnivorous Plants to Sunny, Moist, Nutrient-Poor Habitats. American Naturalist 124:479-497.

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

Glaser, P.H. 1992. Raised bogs in eastern North America - regional controls for species richness and floristic assemblages. Journal of Ecology 80:535-554.

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

Glaser, P.H., G.A. Wheeler, E. Gorham, and H.E. Wright. 1981. The patterned mires of the Red Lake Peatland, Northern Minnesota - Vegetation, Water Chemistry and Landforms. Journal of Ecology 69:575-599.

Gorham, E. and W.H. Pearsall. 1956. Acidity, specific conductivity and calcium content of some bog and fen waters in northern Britain. Journal of Ecology 44:129-141.

Gu, J.-Q., T.N. Graf, D. Lee, H.-B. Chai, Q. Mi, L.B.S. Kardono, F.M. Setyowati, R. Ismail, S. Riswan, N.R. Farnsworth, G.A. Cordell, J.M. Pezzuto, S.M. Swanson, D.J. Kroll, J.O. Falkinham, M.E. Wall, M.C. Wani, A.D. Kinghorn, and N.H. Oberlies. 2004. Cytotoxic and antimicrobial constituents of the bark of *Diospyros maritima* collected in two geographical locations in Indonesia. Journal of Natural Products 67:1156-1161.

Haslam, S.M. 1965. Ecological studies in the Breck Fens I. Vegetation in relation to habitat. Journal of Ecology 53: 599-619.

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

Heidel, B. and S. Laursen. 2003a. Botanical and ecological inventory of peatland sites on the Shoshone National Forest. Wyoming Natural Diversity Database, Laramie, WY. Available online at: http://uwadmnweb.uwyo.edu/wyndd/Reports/pdf_heidel/Shoshone_Peatland_report_2003.pdf.

Heidel, B. and S. Laursen. 2003b. Botanical and ecological inventory of peatland sites on the Medicine Bow National Forest. Wyoming Natural Diversity Database, Laramie, WY. Available online at: http://uwadmnweb.uwyo.edu/wyndd/Reports/pdf_heidel/MedBow_peatland_report_2003.pdf.

Hirsikorpi, M., T. Kaemaeraeinen, T. Teeri, and A. Hohtola. 2002. Agrobacterium-mediated transformation of round leaved sundew (*Drosera rotundifolia* L.). Plant Science 162:537-542.

Hogenbirk, J.C. and R.W. Wein. 1991. Fire and drought experiments in northern wetlands - a climate change analog. Canadian Journal of Botany 69:1991-1997.

Hoshi, Y and K. Kondo. 1998. Chromosome differentiation in *Drosera*, subgenus *rorella*, section *rossolis*. Cytologia 63:199-211.

Hotes, S., P. Poschlod, H. Sakai, and T. Inoue. 2001. Vegetation, hydrology, and development of a coastal mire in Hokkaido, Japan, affected by flooding and tephra deposition. Canadian Journal of Botany 79:341-361.

Hudson, W. 1778. Flora *anglica*. Impensis Auctoris. London, UK.

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

ICPS. 2006. International Carnivorous Plant Society, Seed bank: *Drosera anglica*. Pinole, CA. Available online at: http://www.carnivorousplants.org/seedbank/species/D_anglica.htm.

Jacquemart, A., D. Champluvier, and J. De Sloover. 2003. A test of mowing and soil removal restoration techniques in wet heaths of the high Ardenne, Belgium. Wetlands 23:376-385.

Johnson, J.B. 2000. The ecology of calcareous fens in Park County, Colorado .Thesis. Colorado State University, Fort Collins, CO.

Jones, G.P. and W. Fertig. 1999. Ecological evaluation of the potential Lake Creek Research Natural Area within the Shoshone National Forest, Park County, Wyoming. Unpublished report prepared for the Shoshone National Forest, USDA Forest Service by the Wyoming Natural Diversity Database. Laramie, WY.

Jones, J.A. 2000. Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon. Water Resources Research 36:2621-2642.

Juniper, B.E., R.J.Robins, and D.M. Joel. 1989. The Carnivorous Plants. Academic Press. London, UK.

Kamarainen, T., J. Uusitalo, J. Jalonen, K. Laine, and A. Hohtola. 2003. Regional and habitat differences in 7-methyljuglone content of Finnish *Drosera rotundifolia*. Phytochemistry 63:309-314.

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

Krafft, C.C. and S.N. Handel. 1991. The role of carnivory in the growth and reproduction of *Drosera filiformis* and *D. rotundifolia*. Torrey Botanical Club 118:12-19.

Lemly, J. 2006. Personal communication with a botanist and graduate student at Colorado State University. Collected site data and observations at La Plata County, Colorado occurrence.

LeResche, R.E. and J.L. Davis. 1973. Importance of nonbrowse foods to moose on the Kenai Peninsula, Alaska. Journal of Wildlife Management 37:279-287.

Lloyd, F.E. 1942. The carnivorous plants. Chronica Botanica, Watham, MA.

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

Matthews, R.F. 1994. *Drosera rotundifolia*. *In*: Fire Effects Information System. USDA Forest Service. Rocky Mountain Research Station, Fire Sciences Laboratory. Available online at: http://www.fs.fed.us/database/feis/plants/forb/drorot/.

Mazrimas, J.A. 1987. *Drosera anglica* from the Alkali Swamp, Kauai. Carnivorous Plant Newsletter 16:21-22.

McGraw, J.B. 1986. Seed-bank properties of an Appalachian *Sphagnum* bog and a model of the depth distribution of viable seeds. Canadian Journal of Botany 65:2028-2035.

Mendez, M. and P.S. Karlsson. 1999. Costs and benefits of carnivory in plants: insights from the photosynthetic performance of four carnivorous plants in a subarctic environment. Oikos 86:105-112.

Millett, J., R.I. Jones, and S. Waldron. 2003. The contribution of insect prey to the total nitrogen content of sundews (*Drosera* spp.) determined *in situ* by stable isotope analysis. New Phytologist 158:527-534.

Mills, S. and W. Fertig. 2000. State species abstract: *Drosera anglica* English sundew. Wyoming Natural Diversity Database, Laramie, WY.

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

Montana Natural Heritage Program. 2005. Publications. Available online at: http://nhp.nris.state.mt.us/reports.htm [Accessed: 22 Jan 2005].

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

Moseley, R.K., R. Bursik, and M. Mancuso. 1991. Floristic inventory of wetlands in Fremont and Teton counties, Idaho. Idaho Department of Fish and Game, Boise, ID.

Munz, P.A. 1959. A California Flora. University of California Press, Berkeley, CA.

Murza, G.L. and A.R. Davis. 2003. Comparative flower structure of three species of sundew (*Drosera anglica*, *Drosera linearis*, and *Drosera rotundifolia*) in relation to breeding system. Canadian Journal of Botany 81:1129-1142.

Naiman, R.J. and M.G. Turner. 2000. A future perspective on North America's freshwater ecosystems. Ecological Applications 10:958-970.

National Institute of Health. 2000. Request for comments on substances nominated to the National Toxicology Program (NTP) for toxicological studies and on the testing recommendations made by the NTP Interagency Committee for Chemical Evaluation and Coordination (ICCEC). Federal Register, Notices 65:11329-11331.

NatureServe. 2004. NatureServe Explorer: An online encyclopedia of life. Version 4.0. Available online at: http://www.natureserve.org/explorer [Accessed: 15 July 2004].

Nordbakken, J.F., K. Rydgren, and R.H. Okland. 2004. Demography and population dynamics of *Drosera anglica* and *D. rotundifolia*. Journal of Ecology 92:110-121.

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

Penskar, M.R. and P.J. Higman. 1999. Special plant abstract for *Drosera anglica* (English sundew). Available online at: http://web4.msue.msu.edu/mnfi/abstracts/botany/Drosera_anglica.pdf.

Poff, N.L., M.M. Brinson, and J.W. Day, Jr. 2002. Aquatic ecosystems & global climate change: potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Report prepared for the Pew Center on Global Climate Change.

Popovich, S. 2004. Personal communication with Botanist, Arapaho and Roosevelt National Forests and Pawnee National Grassland.

Poschlod, P. 1995. Diaspore rain and diaspore bank in raised bogs and implications for the restoration of peat-mined sites. *In*: B.D. Wheeler, S.C. Shaw, W.J. Fojt, and R.A. Robertson, R. A., editors. Restoration of Temperate Wetlands, Wiley and Sons, Chichester, UK.

Poulin, M., L. Rochefort, and A. Desrochers. 1999. Conservation of bog plant species assemblages: assessing the role of natural remnants in mined sites. Applied Vegetation Science 2:169-180.

Proctor, J. 2004. Personal communication with Botanist, Medicine Bow-Routt National Forest and Thunder Basin National Grassland.

Reed, P.B. 1996. National list of plant species that occur in wetlands. Draft report. USDI Fish and Wildlife Service, St. Petersburg, FL. Available online at: http://www.fws.gov/nwi/bha/list96.html.

Ridley, H.N. 1930. The dispersal of plants throughout the world. Reeve and Co. Ashford, Kent.

Rivadavia, F., K. Kondo, M. Kato, and M. Hasebe. 2003. Phylogeny of the sundews, *Drosera* (Droseraceae), based on chloroplast rbcL and nuclear 18S ribosomal DNA sequences. American Journal of Botany 90:123-130.

Rocchio, J. and J. Stevens. 2004. Unpublished report by the Colorado Natural Heritage Program, Fort Collins, Colorado. For the USDA Forest Service, Arapaho and Roosevelt National Forest and Pawnee National Grassland, Supervisor's Office.

Schnell, D.E. 1995. A natural hybrid of *Drosera anglica* Huds. and *Drosera linearis* Goldie in Michigan. Rhodora 97: 164-170.

Schnell, D.E. 1999. *Drosera anglica* Huds. vs. *Drosera* x *anglica*: What is the difference? Carinvorous Plant Newsletter 28:107-115.

Schnell, D.E. 2002. Carnivorous plants of the United States and Canada. Timber Press, Portland, OR.

Schulze, W. and E.D. Schulze. 1990. Insect capture and growth of the insectivorous *Drosera rotundifolia* L. Oecologia 82:427-429.

Seeholzer, C. 1993. Biosystematical investigations on Swiss *Drosera* species. Botanica Helvetica 103:39-53.

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

Smart, P.J. 1982. Stratigraphy of a site in the Munsary Dubh Lochs, Caithness, northern Scotland: Development of the present pattern. The Journal of Ecology 70:549-558.

Stevens, P.F. 2001. Angiosperm Phylogeny Website. Accessed 2006 Mar 6. Available at: http://www.mobot.org/MOBOT/research/APweb/.

Stewart, C.N. Jr. and E.T. Nilsen. 1992. *Drosera rotundifolia* growth and nutrition in a natural population with special reference to the significance of insectivory. Canadian Journal of Botany 70:1409-1416.

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

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

Svensson, B.M. 1995. Competition between *Sphagnum fuscum* and *Drosera rotundifolia*: A case of ecosystem engineering. Oikos 74:205-212.

Swales, D.E. 1975. An unusual habitat for *Drosera rotundifolia* L., its over-wintering state, and vegetative reproduction. Canadian Field-Naturalist 89:143-147.

Szumigalski, A.R. and S.E. Bayley. 1997. Net aboveground primary production along a peatland gradient in central Alberta in relation to environmental factors. Ecoscience 4:385-393.

Thoren, L.M. and P.S. Karlsson. 1998. Effects of supplementary feeding on growth and reproduction of three carnivorous plant species in a subarctic environment. Journal of Ecology 86:501-510.

Thoren, L.M., J. Tuomi, T. Kaemaeraeinen, and K. Laine. 2003. Resource availability affects investment in carnivory in *Drosera rotundifolia*. New Phytologist 159:507-511.

Thum, M. 1986. Segregation of habitat and prey in two sympatric carnivorous plant species, *Drosera rotundifolia* and *Drosera intermedia*. Oecologia 70:601-605.

Thum, M. 1988. The significance of carnivory for the fitness of *Drosera* in its natural habitat 1. The reactions of *Drosera intermedia* and *Drosera rotundifolia* to supplementary feeding. Oecologia 75:472-480.

Thum, M. 1989a. The significance of carnivory for the fitness of *Drosera* in its natural habitat. 2. The amount of captured prey and its effect on *Drosera intermedia* and *Drosera rotundifolia*. Oecologia 81:401-411.

Thum, M. 1989b. The significance of opportunistic predators for the sympatric carnivorous plant species *Drosera intermedia* and *Drosera rotundifolia*. Oecologia 81:397-400.

Tiner, R.W. 1984. Wetlands of the United States: current status and recent trends. USDI Fish and Wildlife Service, Washington, D.C.

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

Troendle, C.A. and R.M. King. 1987. The effect of partial and clearcutting on streamflow at Deadhorse Creek, Colorado. Journal of Hydrology 90:145-157.

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

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

USDA Forest Service. 1999. Medicinal Herb Collection Policy for National Forests in Regions One and Four. Available online at: http://www.fs.fed.us/r2/nebraska/gpng/2460_medicinal_herb_collection_policy_r1_r4_1999_0630.html.

USDA Forest Service. 2002. Species Conservation Project: species evaluations and rationales. Region 2 of the USDA Forest Service, Golden, CO. Available online at: http://www.fs.fed.us/r2/projects/scp/evalrationale/index.shtml.

USDA Forest Service. 2004a. Montana Sensitive Plant Species List. Region 1 of the UDSA Forest Service, Missoula, MT. Available online at: http://www.fs.fed.us/r1/projects/wwfrp/sens-species/Sens%20Spp%20List%20Plants%20MT.pdf.

USDA Forest Service. 2004b. Watershed protection and management. Chapter 2520 in Forest Service Manual. USDA Forest Service, Washington D.C. Available online at: http://www.fs.fed.us/im/directives/fsm/2500/2520.doc.

USDA Forest Service. 2005a. Threatened, Endangered, and Sensitive Plants and Animals. Chapter 2670 in Forest Service Manual. USDA Forest Service, Washington, D.C. Available online at: http://www.fs.fed.us/im/directives/fsm/2600/2670-2671.doc.

USDA Forest Service. 2005b. Species Conservation Project: Region 2 Regional Forester's Sensitive Species. Region 2 of the USDA Forest Service, Golden, CO. Available online at: http://www.fs.fed.us/r2/projects/scp/sensitivespecies/index.shtml.

USDA Forest Service. 2005c. USDA Forest Service Technical Guide to Managing Ground Water. Region 2 of the USDA Forest Service, Golden, CO. Available online at: http://www.fs.fed.us/r2/resources/mgr/geology/groundwater/index.shtml.

USDA Forest Service. 2006. Watershed Conservation Practices Handbook. Chapter 2509.25 in Forest Service Handbooks. Region 2 of the USDA Forest Service, Golden, CO. Available online at: http://www.fs.fed.us/cgi-bin/Directives/get_dirs/fsh?2509.25.

USDA Natural Resources Conservation Service. 1999. Percent of land area in histisols. Map ID m4033. USDA, Washington D.C. Available at: http://www.nrcs.usda.gov/technical/land/meta/m4033.html.

USDA Natural Resources Conservation Service. 2004. The PLANTS Database, Version 3.5. Available online at: http://plants.usda.gov/ [Accessed: 15 Jul 2004].

U.S. Fish and Wildlife Service. 1997. Peatland Mitigation Policy Considerations. Region 6, U.S. Fish and Wildlife Service. Colorado Field Office, Lakewood, CO.

Vitt, D.H., S.E. Bayley, and T.L. Jin. 1995. Seasonal-variation in water chemistry over a bog-rich fen gradient in continental Western Canada. Canadian Journal of Fisheries and Aquatic Sciences 52:587-606.

Vyvey, Q.G.M. 1992. Experimental plant ecological research of the Torfbroek at Kampenhout (Belgium): Influence of mowing on fen grassland with *Juncus subnodulosus*. PhD Dissertation. Rijksuniversiteit Te Gent (University of Gent), Belgium.

Weber, W.A. 2003. The middle Asian element in the Southern Rocky Mountain flora of the western United States: a critical biogeographical review. Journal of Biogeography 30:649-685.

WEC. 2004. Survey of World Energy Sources - Peat. World Energy Council. London, UK.

Weeden, N.F. 1975. A Sierra Nevada flora. Wilderness Press, Berkeley, CA.

Weltzin, J.F., J. Pastor, C. Harth, S.D. Bridgham, K. Updegraff, and C.T. Chapin. 2000. Response of bog and fen plant communities to warming and water-table manipulations. Ecology 81:3464-3478.

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

Wilcox, D.A. 1986. The effects of deicing salts on vegetation in Pinhook Bog, Indiana. Canadian Journal of Botany 64:865-874.

Wilcox, D.A. 1995. Wetland and aquatic macrophytes as indicators of anthropogenic hydrologic disturbance. Natural Areas Journal 15:240-248.

Williams, S.E., V.A. Albert, and M.W. Chase. 1994. Relationships of Droseraceae: A cladistic analysis of rbcL sequence and morphological data. American Journal of Botany 81:1027-1037.

Windell, J.T., B.E Willard, D.J. Cooper, S.Q. Foster, C.F. Knud-Hansen, L.P. Rink, and G.N. Kiladis. 1986. An ecological characterization of Rocky Mountain montane and subalpine wetlands. Biological report no. 86(11). 298 p. USDI Fish and Wildlife Service, Washington, D.C.

Winge, O. 1917. The chromosomes, their numbers and general importance. Comptes Rendus Des Travaux Du Laboratoire Carlsberg 13:131-275.

Wolf, E., E. Gage, and D. Cooper. 2006. *Drosera rotundifolia* L. (roundleaf sundew): A technical conservation assessment. Report prepared for the USDA Forest Service, Rocky Mountain Region, Species Conservation Project. Available online at: http://www.fs.fed.us/r2/projects/scp/assessments/droserarotundifolia.pdf.

Wood Jr., C.E. 1955. Evidence for the hybrid origin of *Drosera anglica*. Rhodora 57:105-130.

Wood-Baker, C.S. 1974. Notes on *Aphis audax* H.R.L., 1947, in North Britain with biometric data. Entomologist's Monthly Magazine 110:51-53.

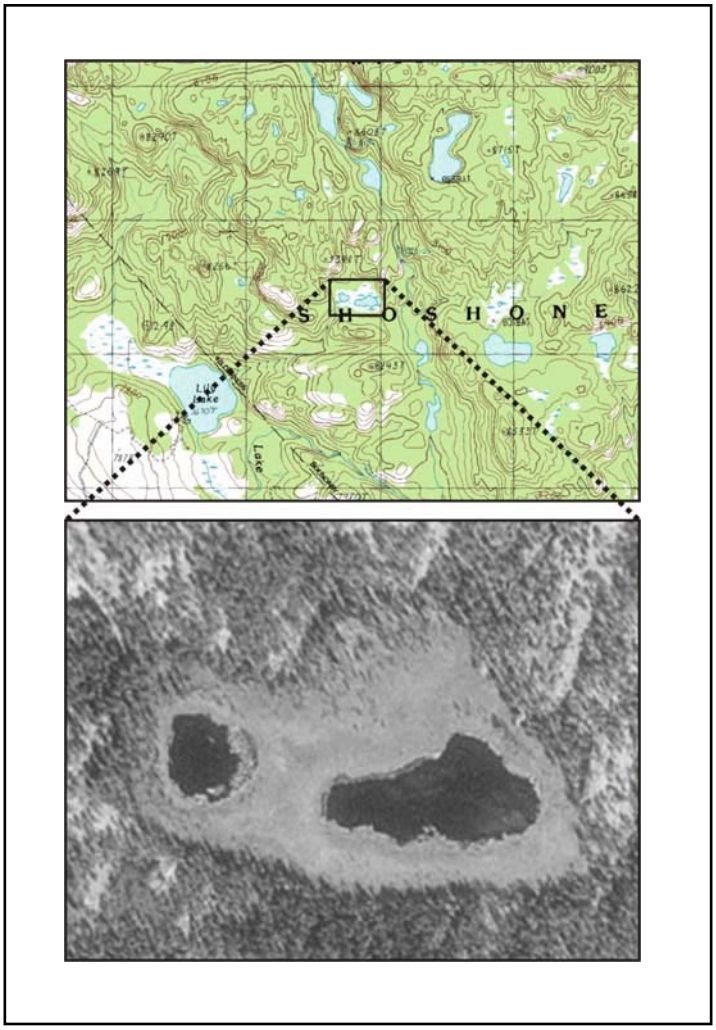
Wynne, F.E. 1944. *Drosera* in eastern North America. Bulletin of the Torrey Botanical Club 71:166-174.

Wyoming Natural Diversity Database. 2004. Plant species of concern. Available online at: http://uwadmnweb.uwyo.edu/WYNDD/ [Accessed: 1 Jan 2004].

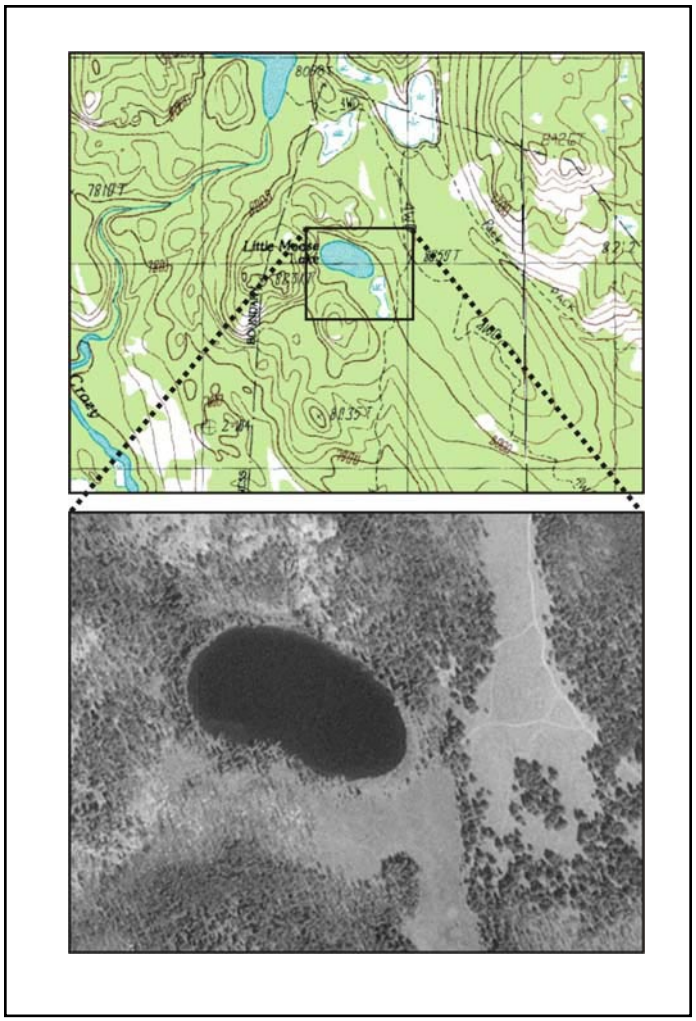
Zoltai, S.C., C. Tarnocai, G.F. Mills, and H. Veldhuis. 1988. Wetlands of Subarctic Canada. Pages 57-96 *in* National Wetlands Working Group. Wetlands of Canada. Polyscience Publications, Montreal, Quebec, Canada.

APPENDIX

Note: Information in this document is for internal USFS use and should not be distributed to the public.



Internal Figure 18. Topographic map and aerial photograph of the Park County, WY 2 (Lily Lake) wetland, Shoshone National Forest, WY.



Internal Figure 19. Topographic map and aerial photograph of Park County, WY 1 (Little Moose Lake) wetland, Shoshone National Forest, WY.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, DC 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.