Drosera rotundifolia L. (roundleaf sundew): A Technical Conservation Assessment

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

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COVER PHOTO CREDIT

Drosera rotundifolia L. (roundleaf sundew). Photograph by David J. Cooper.

Summary of Key Components for Conservation of *Drosera rotundifolia*

Status

Drosera rotundifolia (roundleaf sundew) has a circumboreal distribution and is widespread and abundant in many regions. Globally it is not threatened with extinction in the foreseeable future and is ranked as G5, apparently secure (NatureServe 2004). However, the occurrences located within USDA Forest Service Region 2 are geographically isolated and may represent genetically distinct occurrences. The species is ranked S2, imperiled, in the state of Colorado (Colorado Natural Heritage Program 2004b).

The four verified Region 2 occurrences of *Drosera rotundifolia* are located in fens in Colorado. Three occurrences are in sites with floating mats, and one is in a rare iron fen. Fens are uncommon in the Rocky Mountains and are critical to the survival of these *D. rotundifolia* occurrences. *Drosera rotundifolia* 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 rotundifolia* are events that alter the hydrologic function of fens. Water-saturated conditions produced by perennial groundwater discharge are critical for maintaining slow rates of organic matter decomposition and nutrient turnover in fens. Activities that disrupt, divert, augment, or redistribute groundwater or surface flow to and through a fen have the potential to alter its ecosystem function and floristic composition. 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 plant communities. Activity within a fen can significantly impact the quality and abundance of these microsites. For example, trampling by cattle, people, vehicles and native animals can break apart floating peat mats that provide *Drosera rotundifolia* habitat.

Any change in the nutrient budget of a fen can also significantly alter site suitability for *Drosera rotundifolia*. Being adapted to nutrient-poor environments, *D. rotundifolia* would likely suffer from fertilization via atmospheric deposition of nitrogen, addition of livestock excrement, or an increase 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 rotundifolia* is to ensure that the groundwater and surface water flow regimes remain unaltered. This necessitates a full understanding of the hydrologic processes in sites supporting *D. rotundifolia* 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 rate and water levels in fens.

The integrity of the peat body in which *Drosera rotundifolia* 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 rapidly. The peat body's structure provides much of the microsite variation critical to fen plants, including *D. rotundifolia*.

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, and water holding capacity, are altered when inorganic sediment is added. Any action that leads to the input of significant amounts of mineral sediment to a fen will alter the microsite hydrologic and geochemical regimes in the peat body, potentially reducing habitat suitability for *Drosera rotundifolia*.

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

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INTRODUCTION

This assessment is one of many being produced to support the Species Conservation Project for the Rocky Mountain Region (Region 2), USDA Forest Service (USFS). *Drosera rotundifolia* L. (roundleaf 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 as a sensitive species (USDA Forest Service 2005). The USFS lists *D. rotundifolia* as a sensitive species in Region 2 (USDA Forest Service 2002). 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. rotundifolia* 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

Our goal in this document is to provide a comprehensive and synthetic review of the biology, ecology, and conservation status of *Drosera rotundifolia* 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. rotundifolia* occurs only in specific types of wetlands, we focus 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. In this assessment, we do not seek to develop specific management recommendations. Rather we provide the ecological background upon which management must be based and focus on the consequences of changes in the environment that result from management (i.e., management implications).

Scope and Information Sources

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

The emphasis of this assessment is on *Drosera rotundifolia* 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, when possible we have incorporated information regarding evolutionary and biogeographic aspects of both the species and the wetland types in which it occurs. These broader perspectives are essential for developing realistic assessments of current and future conservation threats.

Treatment of Uncertainty

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 as this one, it is important to explicitly address issues of uncertainty.

Though widely distributed globally, *Drosera rotundifolia* occurs at only a very few sites within Region 2. Unfortunately, there are few quantitative data on many aspects of *D. rotundifolia* 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. rotundifolia* has been extensively studied elsewhere. We have drawn upon these studies to make inferences about the species in Region 2, but because it is easy to misapply research findings outside of their original ecological context, we have been judicious in the use of these data.

Considering the lack of rigorous, experimental research conducted on *Drosera rotundifolia* within Region 2, we have relied heavily upon our knowledge of the particular wetland types where the species occurs. In concert with insights provided by other scientists and managers and careful extrapolation of work conducted outside the region, we provide a first approximation of the species' biology, ecology, and conservation status. To help readers evaluate our conclusions, we explicitly note the strength of evidence for particular ideas throughout the assessment and, where possible, provide alternative hypotheses.

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 (USDA Forest Service 2004).

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 rotundifolia* is G5, globally secure, as a result of its scattered distribution over a very broad range, and the variety that occurs in Region 2, *D. rotundifolia* var. *rotundifolia*, is ranked T5, a globally secure infraspecific taxon (NatureServe 2004).

Federal status

The National Heritage Status Rank for *Drosera rotundifolia* is N5, secure, within the United States and Canada (NatureServe 2004). The species is neither listed nor a candidate for listing under the Endangered Species Act.

USDA Forest Service regional designation

USDA Forest Service Region 2, which encompasses Colorado, and parts of Kansas, Nebraska, South Dakota, and Wyoming, lists *Drosera rotundifolia* as a sensitive species due to its disjunct distribution and restriction to rare habitats that are unusually sensitive to disturbance (USDA Forest Service 2002).

State rank

The Colorado Natural Heritage Program ranks *Drosera rotundifolia* as S2, imperiled within the state, because of rarity (6 to 20 occurrences, or 1,000 to 3,000 individuals) and/or other factors that demonstrably make the species very vulnerable to extinction throughout its range within the state (Colorado Natural Heritage Program 2004b). The other states within Region 2 do not rank *D. rotundifolia*.

Outside of Region 2 *Drosera rotundifolia* is listed as critically imperiled (S1) in Iowa, Tennessee, Alabama, and Georgia; imperiled (S2) in Illinois and Delaware; and vulnerable (S3) in Indiana, West Virginia, North Carolina, and Maryland. These rankings are due to the species' restricted range, relatively few (often less than 80) occurrences in the state, recent and widespread declines, or other factors making it vulnerable to extirpation. *Drosera rotundifolia* is apparently secure (S4) in Rhode Island, Newfoundland, and Labrador (Canada), where it is uncommon but not rare, with some cause for long-term concern due to declines or other factors. Six Canadian provinces – Alberta, Manitoba, Ontario, Quebec, Prince Edward Island, and Nova Scotia – list *D. rotundifolia* as secure (S5) because it is common, widespread, and abundant (NatureServe 2004).

The variety *Drosera rotundifolia* var. *rotundifolia*, the taxon found in Region 2, is listed as vulnerable (S3) in North Carolina and secure (S5) in New Jersey, British Columbia, Saskatchewan, and Prince Edward Island. The variety *D. rotundifolia* var. *comosa* is listed as critically imperiled (S1) in New Brunswick. 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

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

Drosera rotundifolia is an obligate wetland species (i.e., restricted to wetland habitat) (Reed 1988). 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 impacting 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 series 2520 (USDA Forest Service 2004) and the USDA Forest Service Technical Guide to Managing Ground Water (USDA Forest Service 2005) provide agency-wide guidance on the definition, protection, and management of wetlands. Wetland management directives specific to Region 2 are covered by the Forest Service Handbook series 2509.25 (USDA Forest Service 2006). 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 personal communication 2004). The U.S. Fish and Wildlife Service addresses the protection of the wetland types specific to *Drosera rotundifolia* 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 *Drosera rotundifolia* occurrences and habitat.

Biology and Ecology

Classification and description

Systematics and synonymy

Drosera rotundifolia L. 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 2002).

Three North American varieties of *Drosera rotundifolia* are recognized: var. *rotundifolia*, var. *camosa* Fernald, and var. *gracilis* Laestad (USDA Natural Resources Conservation Service 2002). *Drosera rotundifolia* var. *rotundifolia* is found in Alaska, across most of Canada, in the Pacific Northwest and Great Lakes regions of the United States, along the Atlantic and Gulf coasts, and in Colorado. Within the United States, *D. rotundifolia* var. *camosa* is only found in the northeast, and *D. rotundifolia* var. *gracilis* is found only in Alaska.

History of species

Carl Linnaeus originally described *Drosera rotundifolia* in 1753. The lectotype specimen is housed in the herbarium of the Linnean 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). The majority of the current research on *D. rotundifolia*, from the genetic level up through ecosystem processes such as climate change and aerial nitrogen deposition, has occurred in Europe. While relatively little research has been conducted on this species in the western United States, recent work includes a dissertation on its pollination ecology in California (Engelhardt 1998), a botanical survey of a Colorado occurrence (Rocchio and Stevens 2004), a genetic study of Colorado and California occurrences (Cohu 2003), and a hydrologic analysis of a fen supporting another Colorado occurrence (Cooper 2003).

Morphological characteristics

Drosera rotundifolia is an herbaceous perennial plant with a slender vertical axis about 3 cm long in plants grown in full sun, and up to 5 cm long in shade-grown plants (**Figure 1**). The leaves attach spirally in a basal, prostrate rosette of long, flat, narrow, petioled, pubescent leaves up to 8 cm across (**Figure 2**). The leaves are divided into two parts: a linear petiole up to 4 cm in length and a terminal obovate to orbicular blade modified into a trapping mechanism up to 2 cm across (Munz 1959). The petioles are green, hairy (sometimes glabrous), up to 3 cm long, 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 in the entrapment of 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

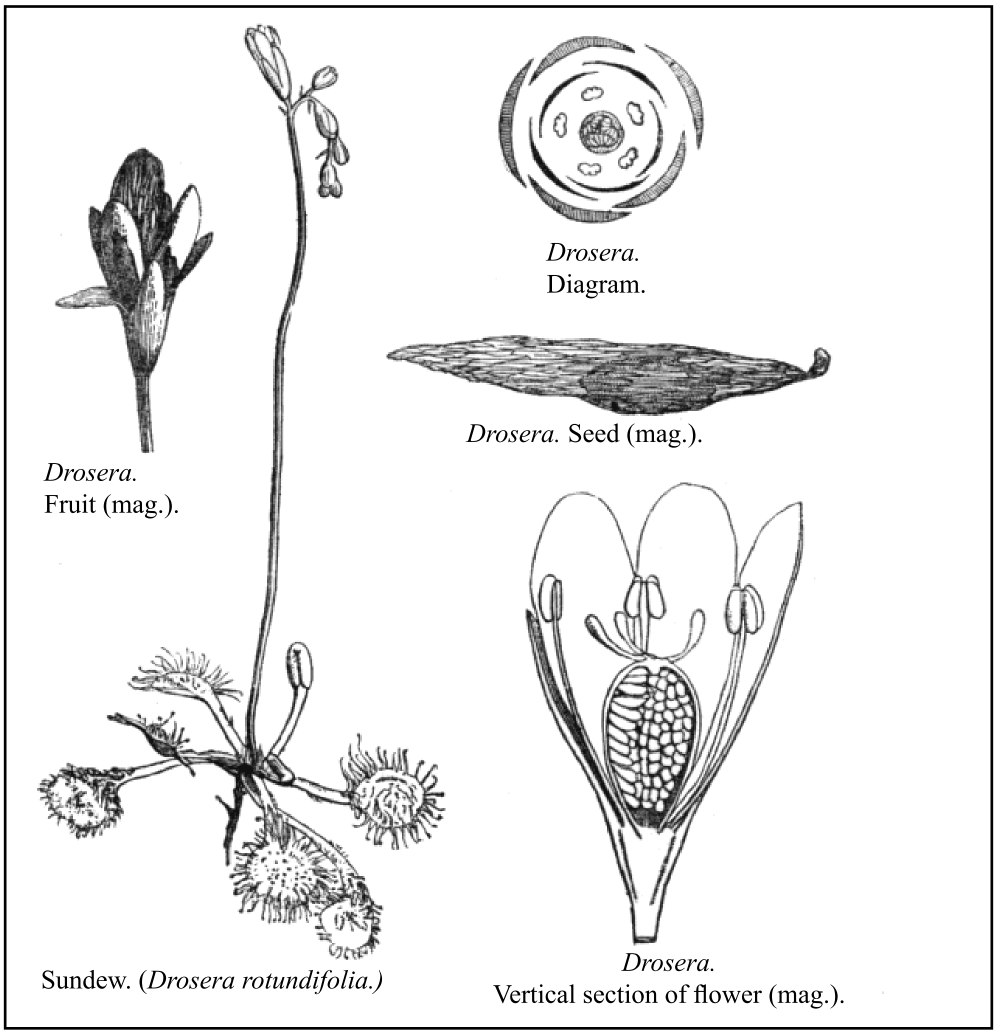

Figure 1. Key *Drosera rotundifolia* structures. Source: Watson and Dallwitz (2000), used with permission).

Figure 2. Rosette and leaves of *Drosera rotundifolia*. Photograph by E. Wolf.

and glandular hairs (Swales 1975). The leaves of *Drosera rotundifolia* possess a unique mechanism for bending: once entrapment has occurred, the leaf petiole folds over the captured prey preventing 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 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 rotundifolia* is a single, one-sided, cymose raceme that terminates in a naked, glabrous scape 5 to 12 cm in height. The flowers are white, 10 to 12 mm in diameter, radially symmetrical (actinomorphic), and 15 to 25 flowers occur on each flowering scape (**Figure 1**). The flowers are hermaphroditic and have a calyx composed of a series of five united, oblong, obtuse, and imbricated sepals that are 4 to 5 mm long and a corolla that is composed of five free, imbricated, ephemeral, and spatulate petals that are slightly longer than the sepals. The androecium includes five stamens that have free, filiform filaments and extrorse anthers (Weeden 1975). The calyx, corolla, and stamens are persistent.

Pollen tetrads are 60 µm across, with single grains 35 µm, exine with spines about 3 to 5 µm; the spinules are dimorphic, the smaller 0.5 µm and more frequent, the larger 2 µm long (Erdtman et al. 1963, Chanda 1965). The gynoecium is described as a three part, hypogynous, superior ovary with three free styles (Munz 1959). The plant produces a 3-valved loculicidally dehiscent capsule containing numerous black, ovoid, sigmoid-fusiform seeds 1.0 to 1.5 mm long with fine longitudinally striate markings that shine with a metallic luster (Abrams 1944). The fruit frequently persists entire, freeing the seeds when it rots. The spindle-shaped seeds have a mean air-dry weight of 10 to 20 µg (Crowder et al. 1990).

Distribution and abundance

Drosera is a widely distributed genus, with over 90 species occurring globally. The center of diversity is Oceania, with over 40 species found in southwest Australia alone (Juniper et al. 1989). *Drosera rotundifolia* is one of the most broadly distributed *Drosera* species, occurring throughout much of the Holarctic (**Figure 3**; Hulten 1968, Schnell 2002). In Eurasia, *D. rotundifolia*'s range extends from Kamchatka, Japan, and the Korean peninsula in the east through Siberia into Scandinavia, the British Isles, and Iceland in the west (Crowder et al. 1990).

Drosera rotundifolia is broadly distributed in North America; occurrences are found throughout Canada and in 35 U.S. states, from California in the west, through the northern Great Plains, the Great Lake states, and along the East and Gulf coasts (Schnell 2002, NatureServe 2004). Notably, the distribution of *D. rotundifolia* closely matches the main distribution of peat-forming ecosystems in North America (**Figure 4**). Peatlands 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.

Of the three recognized North American varieties, *Drosera rotundifolia* var. *rotundifolia* is the most widespread throughout North America and the only variety that occurs in Region 2. The other

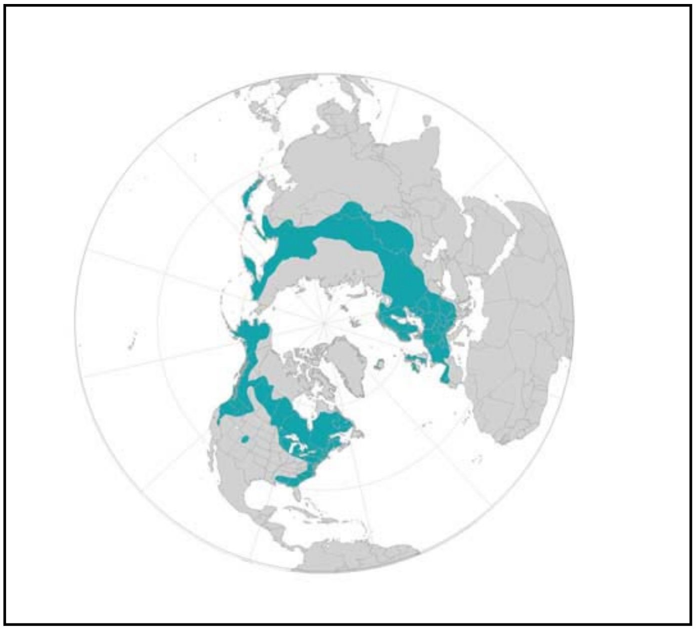

Figure 3. Distribution of *Drosera rotundifolia* in the northern hemisphere. Occurrences in any given region tend to be localized and can be widely separated from adjacent occurrences. Note that the Region 2 occurrences, in Colorado, are widely disjunct from other known occurrences.

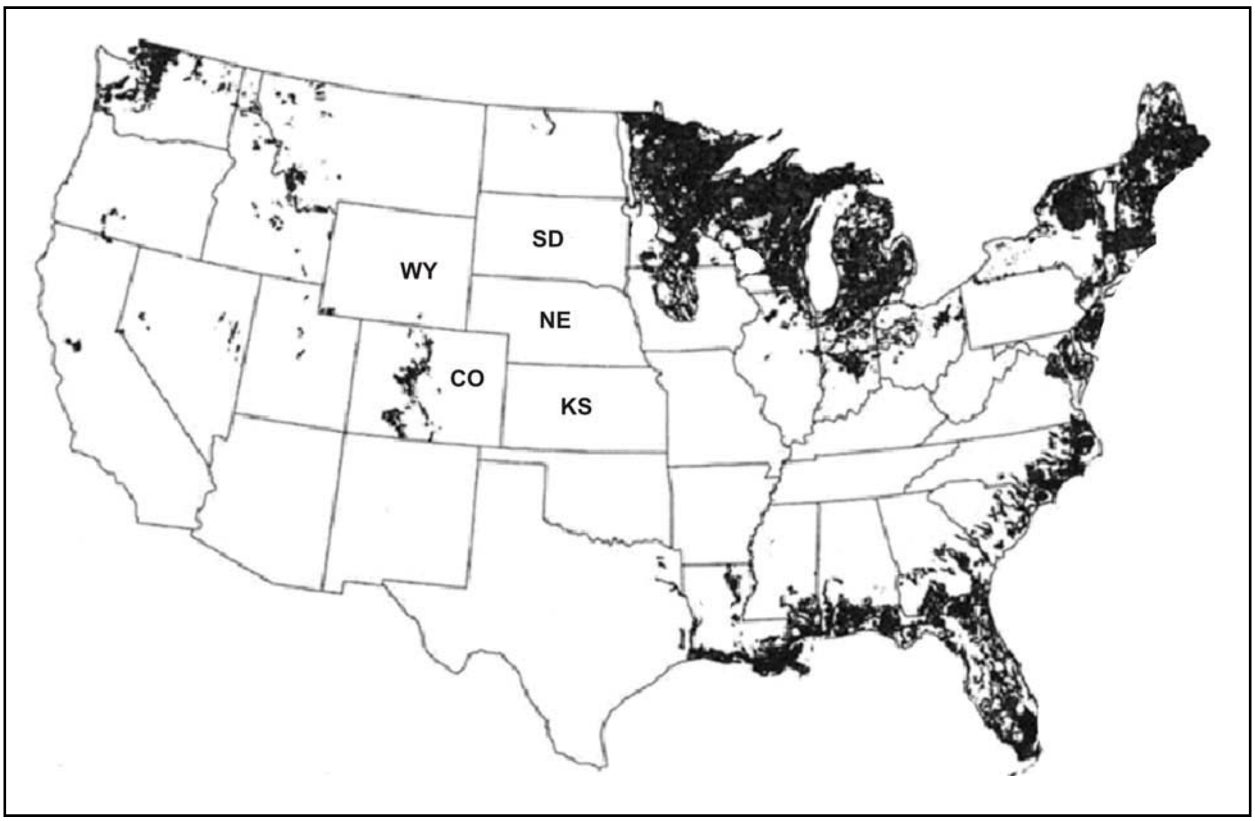

Figure 4. Distribution of main peat-forming areas in the continental United States. Source: USDA Natural Resources Conservation Service (1999), used with permission.

two, *D. rotundifolia* L. var. *gracilis* Laestad and *D. rotundifolia* L. var. *comosa* Fern, have limited distributions, occurring only in Alaska and the northeast United States, respectively (USDA Natural Resources Conservation Service 2002).

Only seven locations supporting *Drosera rotundifolia* occurrences have been reported in Region 2, and all of these are from National Forest System lands in Colorado (**Figure 5**, **Table 1**). Four of these occurrences have been verified; sites 1 and 2 are from Jackson County, site 5 is from Grand County, and site 7 is from Gunnison County (**Table 1**). These occurrences are disjunct from one another and from occurrences outside of Region 2 (**Figure 5**). The three unverified occurrence records (sites 3, 4, and 6 in **Table 1**) are each based on a single Colorado Natural Heritage Program account. A recent attempt to field verify site number 6 (**Figure 5**) failed to find any *D. rotundifolia* or suitable habitat (Popovich personal communication 2006). For this reason, the occurrence of *D. rotundifolia* at site 6 is probably a false report. In light of the probable falseness of the site 6 report, sites 3 and 4 should be considered non-occurrences until they are field checked and a *D. rotundifolia* occurrence is verified.

Globally, *Drosera rotundifolia* is found across a broad elevation range, from near sea level to nearly 3,000 meters (Crowder et al. 1990, Colorado Natural Heritage Program 2004a). Region 2 occurrences and the peatlands they occupy are at relatively high elevation, 2,680 to 2,930 meters, because the relatively warm and dry climate of the region limits peat accumulation rates in most low elevation sites (Cooper 1996). Stable and consistently high water tables are necessary for peat accumulation and thus for *D. rotundifolia*, and these occur only in favorable microclimatic and hydrogeomorphic settings, which are limited within Region 2.

Abundance estimates for Region 2 occurrences are generally lacking, but some rough estimates exist for two of the seven sites. Rocchio and Stevens (2004) estimated that approximately 1,000 to 2,000 plants occurred at site 5 in Grand County. Steve Popovich (personal communication 2006), recalls that this site contained thousands more plants in 2004 than the Rocchio and Stevens estimate. In addition, he recently estimated that the Jackson County site 1 occurrence supports approximately 10,000 plants (Popovich personal communication 2006). This occurrence covers 1,980 square meters (0.49 acres) and is the largest documented occurrence of *Drosera rotundifolia* in Region 2. The population estimate for this single site exceeds the state-wide estimate of 5,000 to 7,000 total plants given by Rocchio and Stevens (2004) and underscores the difficulty of making a regional estimate with the current lack of local abundance data. (There are no rigorously collected census data supporting these limited estimates of local abundance.)

Population trends

Estimates of *Drosera rotundifolia* occurrence sizes in Region 2 are mostly anecdotal. Most of the known locations have been rarely visited since initial collection or observation, and no quantitative data are available to confidently estimate population trends. The Gunnison County iron fen occurrence was the first occurrence discovered in Colorado, and the fen it occupies is perhaps the best understood hydrologically and geochemically (Cooper 2003). Although the fen has been extensively studied (Fall 1997, Cooper et al. 2002, Cooper 2003), no research has focused on *D. rotundifolia* specifically, and no estimates of the number of individuals have been made.

The occurrence in Grand County was estimated to support 1,000 to 2,000 individuals in 2002 and 2003 (Rocchio and Stevens 2004) or perhaps many thousands (Popovich personal communication 2006). A visit on September 3, 2004, by David Cooper and Steve Popovich found fewer than 10 plants, indicating enormous interannual variance in the number of individuals. The fen has recently had a dramatic increase in anthropogenic disturbance, due largely to visitor trampling. However, it is unclear how significantly this influences occurrence size and variability. Anomalously, cool and wet conditions during the summer of 2004 may also have influenced population size, perhaps by influencing seed germination and adult plant emergence (Popovich personal communication 2004).

Reproductive biology and autecology

Reproduction

Drosera rotundifolia can reproduce both sexually and asexually. Asexual reproduction occurs when leaf buds form plantlets. Alternatively, axillary buds found below the rosette can form a secondary rosette, with two genetically identical individuals resulting following the decay of the joining stem.

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

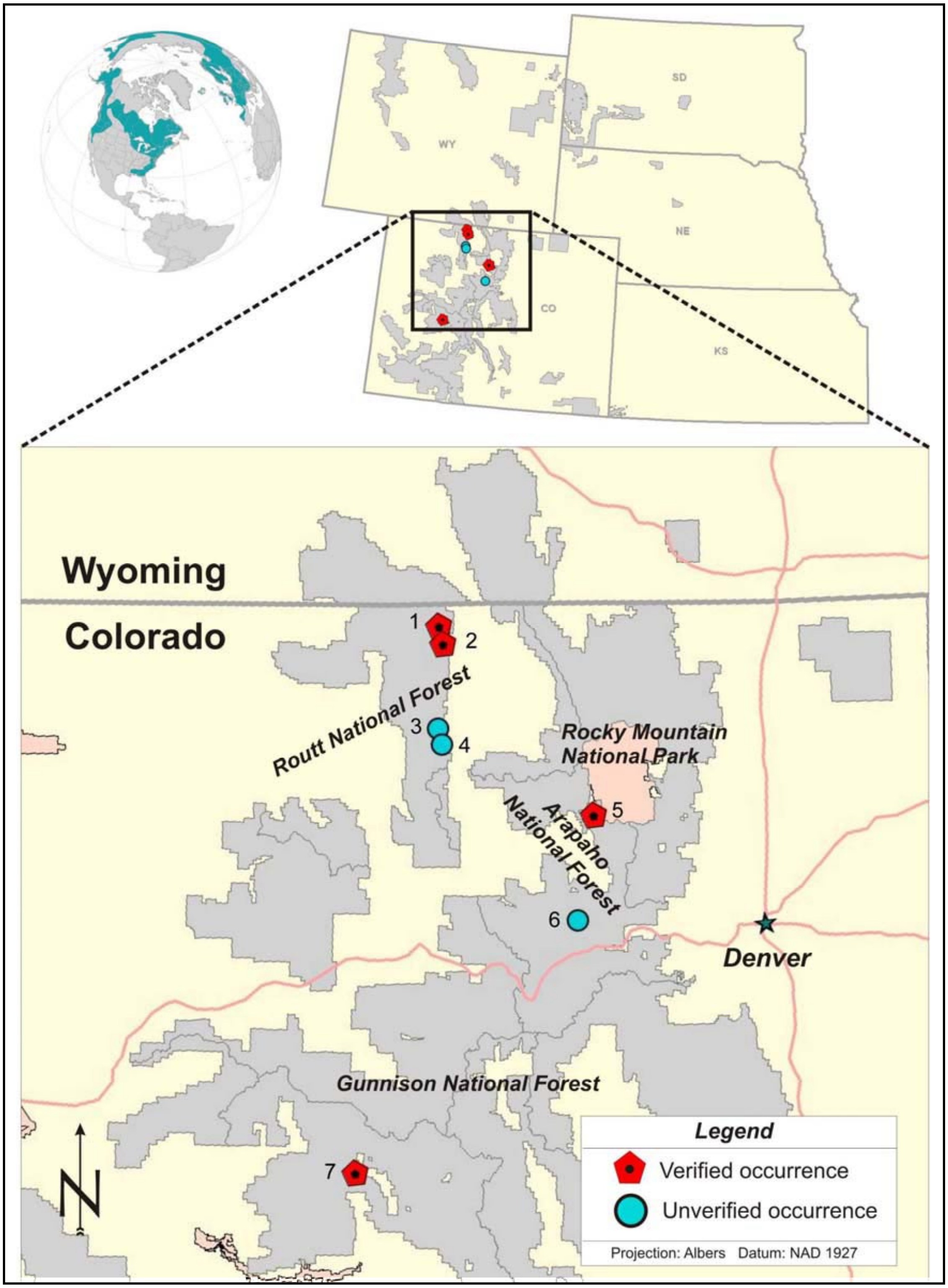

Figure 5. Distribution of *Drosera rotundifolia* within USDA Forest Service Region 2. Four of the seven occurrences reported have voucher specimens deposited in herbaria (red pentagons); the remaining three sites are identified in Colorado Natural Heritage Program (2004a) records, but are unsubstantiated by voucher specimens or photographs (blue circles). Information for individual locations, ordered by site number, is provided in **Table 1**. Sources: Colorado Natural Heritage Program, Rocky Mountain Herbarium, Colorado State University Herbarium, University of Colorado Herbarium.

Table 1. List of USDA Forest Service Region 2 herbaria and Colorado Natural Heritage Program (CNHP) element occurrence records for *Drosera rotundifolia*. Multiple records (e.g., herbaria and CNHP) exist for several occurrences. The locations of occurrences listed in the table are linked via the map key number to **Figure 5**.

Record source	Map key	In-text reference	Accession/ record number	Management	Collector	Record/ collection date
CNHP	1	Jackson County site 1	PDDRO02070*007	Routt National Forest	N. Barrett	9/1/1992
CNHP	1	Jackson County site 1	PDDRO02070*005	Routt National Forest	N. Barrett and M. Zimmerman	8/13/1996
University of Colorado Herbarium	1	Jackson County site 1	499695	Routt National Forest	N. Lederer	7/28/2001
University of Colorado Herbarium	2	Jackson County site 2	443092	Routt National Forest	B. Neely and A. Carpenter	8/3/1989
Colorado State University Herbarium	2	Jackson County site 2	53451	Routt National Forest	B. Neely and A. Carpenter	8/3/1989
CNHP	2	Jackson County site 2	PDDRO02070*002	Routt National Forest	B. Neely and H. Richter	8/22/1991
University of Colorado Herbarium	2	Jackson County site 2	468751	Routt National Forest	J. Sanderson	9/10/1997
CNHP	3	Unverified site 3	PDDRO02070*009	Routt National Forest	C. Stafford and C. Quinn	7/3/1996
CNHP	4	Unverified site 4	PDDRO02070*008	Routt National Forest	S. Franklin	7/1/1996
Colorado State University Herbarium	5	Grand County	84788	Arapaho National Forest	S. Popovich	7/15/2002
CNHP	5	Grand County	PDDRO02070*010	Arapaho National Forest	J. Rocchio and J. Stevens	8/1/2003
CNHP	6	Unverified site 6	PDDRO02070*006	Arapaho National Forest	C. Samuelson	6/1/1993
University of Colorado Herbarium	7	Gunnison County	318670	Gunnison National Forest	B. Johnston et al.	8/4/1978
University of Colorado Herbarium	7	Gunnison County	429567	Gunnison National Forest	W. Weber	6/22/1987
University of Colorado Herbarium	7	Gunnison County	318660	Gunnison National Forest	W. Keammerer et al.	7/23/1987
University of Colorado Herbarium	7	Gunnison County	58042	Gunnison National Forest	B Johnston et al.	8/4/1978
Rocky Mountain Herbarium	7	Gunnison County	339954	Gunnison National Forest	B. Johnson	8/4/1978
CNHP	7	Gunnison County	PDDRO02070*001	Gunnison National Forest	B. Johnston et al.	6/22/1987

– 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 rotundifolia, 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 (Thoren et al. 2003), and the photosynthetic cost of the investment in carnivory is only offset in sunny, wet settings. Thus in open, 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 rotundifolia can capture and digest a wide range of arthropods. In a study of prey capture by different *Drosera* species, *D. rotundifolia* trapped individuals from over 13 different arthropod orders, with Dipterans (flies) being the most common prey type (**Figure 6**).

Studies to determine the proportion of carnivory-derived nitrogen within *Drosera rotundifolia* plants 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 showed that flower and seed production in *Drosera rotundifolia* increased with artificially elevated feeding rates (Darwin 1878). Other investigations have corroborated the correlation between increased prey consumption and increased growth (Thum 1988, Krafft and Handel 1991, Thoren and Karlsson 1998). However, *D. rotundifolia* can grow, survive, and reproduce in the absence of prey. One study (Stewart and Nilsen 1992) found that there was no difference in growth between plants where insects were excluded and plants that trapped prey. 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. In a separate study it was found that 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 rotundifolia* (and other carnivorous plants) may be able to subsist for the duration of a

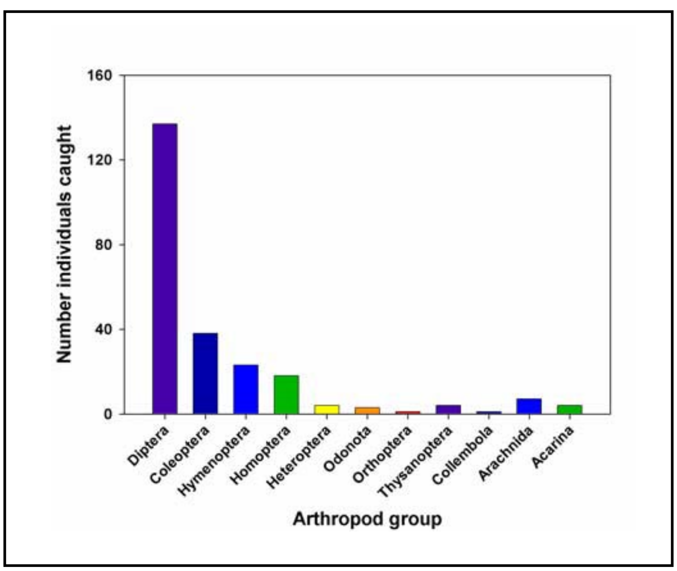

Figure 6. Arthropod diversity of *Drosera rotundifolia* prey. Data from Achterberg (1973), as presented in Juniper et al. (1989), used with permission.

scientific study without the nutrients absorbed from insects, their long-term, evolutionary strategy for survival appears dependent on carnivory (Ellison and Gotelli 2001).

Pollinators and pollination ecology

Drosera rotundifolia is an autogamous (self-pollinating) species. Throughout most of its range, the flowers of *D. rotundifolia* 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 rotundifolia* does not possess functional nectaries, which serve to attract insect pollinators. A study of insect visitation to a chasmogamous occurrence in California reported no activity that would result in pollen transport (Engelhardt 1998).

Dispersal mechanisms

Drosera rotundifolia has no specific long distance dispersal mechanism, but seeds 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 small weight allows them to be blown a short distance by gusts of wind. Foraging animals such as deer or bear may ingest seeds and defecate them at a different location. The small, light seeds may also stick to birds' feet or feathers, or mammals' fur as they move past the plant (Crowder et al. 1990).

Seed viability and germination requirements

A persistent soil seed bank is reported for *Drosera rotundifolia* (McGraw 1986, Poschlod 1995). This seed bank may be especially important in establishing *D. rotundifolia* following disturbance. The seeds are viable for up to four years (Crowder et al. 1990). The highest germination rate (95 percent) was achieved with seed that was stored for eight weeks in a moist, dark environment at 10 °C and then kept in a greenhouse with 14 h of daylight between 18 to 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).

Engelhardt (1998) found that while cold stratification is not necessary for germination, it does increase germination success. In his study of *Drosera rotundifolia* in Sequoia National Park, CA, he achieved mean germination rates of 26 to 57 percent for several treatments. The germinability of *D. rotundifolia* seeds rapidly decreases with burial depth greater than approximately 5 mm (**Figure 7**; Cambell and Rochefort 2003).

Cryptic phases

During its up-to-five-year lifespan, *Drosera rotundifolia* passes through two life stages that may be considered cryptic: dormant seeds within the soil seed bank (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 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

Vesicular-arbuscular mycorrhiza are reported from a study in Czechoslovakia (Mejstrik 1976).

Hybridization

Hybridization within the Droseraceae appears fairly common and has been used to explain the origin

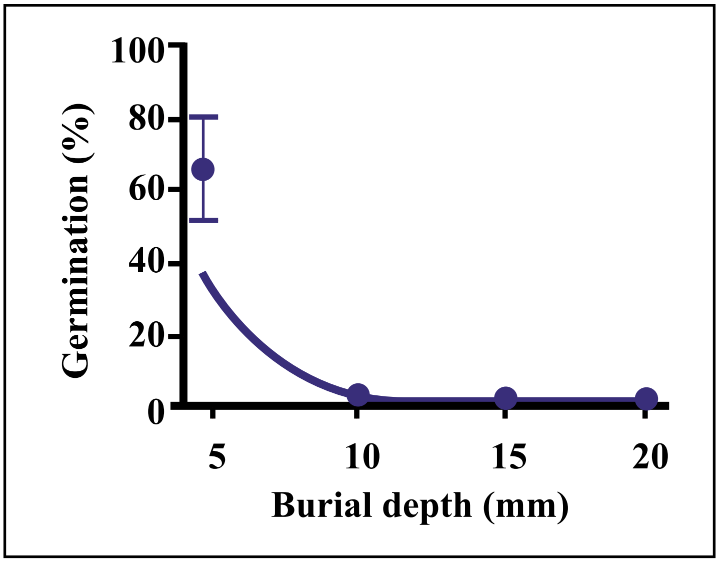

Figure 7. Seed germination of *Drosera rotundifolia* in relation to burial depth. Modified from Cambell and Rochefort (2003), used with permission.

Figure 8. Hibernacula of *Drosera rotundifolia.* Photograph by D. Rice, used with permission.

of several *Drosera* species. Wood (1955) hypothesized that *D. anglica* originated as a hybrid between *D. linearis* and *D. rotundifolia*. However, a recent comparison of floral structure finds no evidence to support this assertion (Murza and Davis 2003).

Where they co-occur, *Drosera rotundifolia* has been shown to hybridize with *D. anglica* (Hulten 1968). The resulting hybrid, *Drosera x obovata* Mert. & Koch, is sterile and exhibits morphology intermediate between the parent species (Wood 1955, Schnell 2002). Since no other species of *Drosera* are present in Colorado, where all known occurrences of *D. rotundifolia* in Region 2 exist, hybrids are unlikely (NatureServe 2004).

Demography

The only demographic data available for *Drosera rotundifolia* in Region 2 are the estimates of the number of individuals in the Grand County occurrences, which are addressed in the above Population trends section.

Mortality of *Drosera rotundifolia* 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 *D. rotundifolia*, 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. rotundifolia* 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).

Life history characteristics

We have identified four main life stages for *Drosera rotundifolia*: seed, seedling, mature plant, and 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 rotundifolia* occurs, temporal and spatial fluctuations in water availability and competition with other plants can significantly influence on the growth and survival of the species. In a Norwegian study of *D. rotundifolia*, 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 reduce the availability of insect prey (Nordbakken et al. 2004).

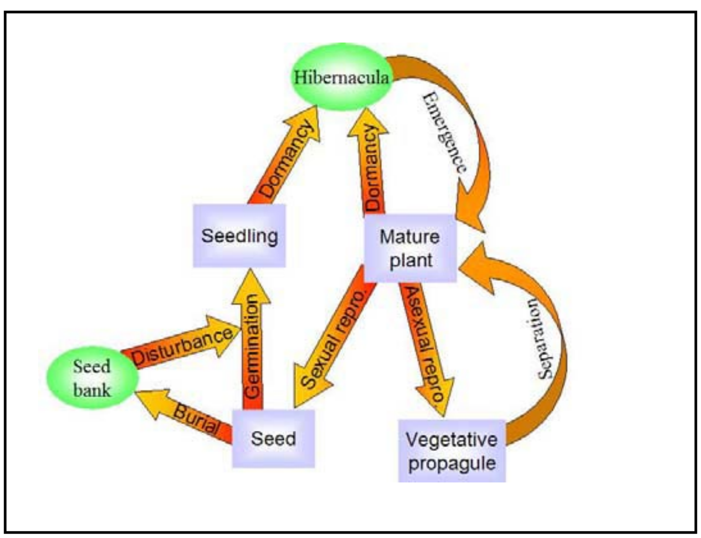

Figure 9. Life cycle diagram for *Drosera rotundifolia*.

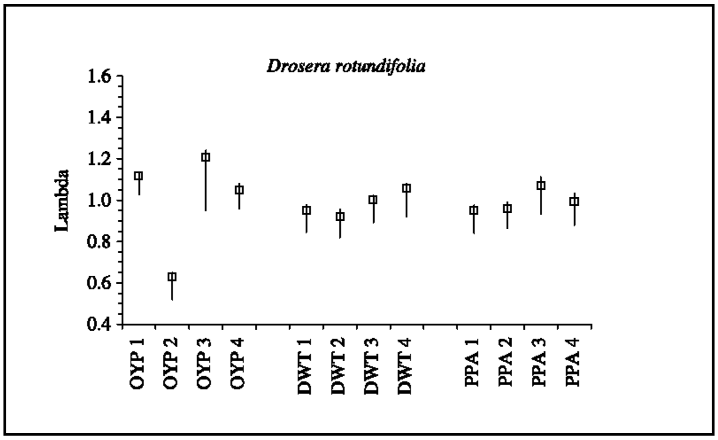

Figure 10. Population growth rate (λ, +99% confidence intervals) for each of four one-year-periods (OYP1-OYP4) and quartiles for depth to water table (DWT) and peat production ability (PPA). Source Nordbakken et al. (2004), used with permission.

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 low population growth rate of *Drosera rotundifolia* in the moderately shallow water table class (DWT class 2; 5.7 to 8.5 cm) indicates its sensitivity to inundation in hollows. The significantly higher growth rate on hummocks with deeper water tables (DWT class 4; 13.4 to 43.0 cm) shows a preference to sites within the capillary fringe.

The episodic occurrence of unfavorable climate conditions regulated *Drosera rotundifolia* growth in ombrotrophic bogs. Occurrences only rarely and locally reached sufficient concentrations where density-dependent birth and mortality rates regulated population size (Nordbakken et al. 2004).

Genetic characteristics and concerns

Drosera rotundifolia chromosomes (2n = 20) can be extracted using a relatively simple technique (Bekesiova et al. 1999). The ability to isolate the specific genes that 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. rotundifolia*, in order to preserve critical genetic resources (Kamarainen et al. 2003).

Genes from *Drosera 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. However, the significant physiological costs to the plant of growing and maintaining such specialized structures may outweigh their benefits (Ellison and Gotelli 2001).

Drosera rotundifolia produces the chemicals 7-methyljuglone and plumbagin, both of which are napthaquinones. The specific function of these secondary compounds in *D. rotundifolia* 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. rotundifolia* and other *Drosera* species have long traditions of use as folk medicines.

A preliminary study on the genetic variability of *Drosera rotundifolia* indicates little genetic variation within and between three Colorado occurrences and one from California (Cohu 2003). The lack of variability within occurrences is expected for species whose primary mode of reproduction is asexual, such as *D. rotundifolia*, due to a lack of genetic recombination.

The lack of variability between the Colorado occurrences and the distal and disjunct occurrence in California may indicate that these occurrences are the peripheral remnants of a once-larger and more connected metapopulation. Peripheral populations at the extremes of a species' spatial range can exhibit very low genetic diversity within peripheral populations and between other peripheral populations (Durka 1999).

Commercially available specimens of *Drosera rotundifolia* exhibited much greater genetic diversity than any of the plants sampled from natural populations (**Table 2**). This indicates that greater diversity occurs within *D. rotundifolia*'s range, and broader genetic sampling could reveal patterns of diversity that may illuminate the ancestry and origins of the occurrences in Region 2 (Cohu 2004).

Factors limiting survival and reproduction

Climatic conditions (i.e., moisture, temperature) are the primary controls of *Drosera rotundifolia* population size and growth. Populations are rarely and only locally regulated by density-dependent recruitment and mortality rates (Nordbakken et al. 2004). Numerous studies have confirmed the importance of prey as a limiting factor for various fitness parameters (Thum 1988, Thum 1989a, Krafft and Handel 1991, Thoren and Karlsson 1998).

Community and ecosystem ecology

General habitat characteristics

Drosera rotundifolia is an obligate wetland species that requires continuously moist or saturated soils and is found in sites with shallow water table depths (Reed 1988). The roots cannot tolerate desiccation, and the rooting zone (<6 cm below ground surface) must remain moist to saturated. *Drosera rotundifolia* can withstand ground frost with its leaves uncurled, and this occurs often within its boreal distribution (Crowder et al. 1990). Throughout its range, *D. rotundifolia* is typically found in nutrient poor peatlands including ombrotrophic (rain-fed) bogs, poor fens, and along the margins of acidic ponds (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). The species occurs in both continental and maritime climates (Haslam 1965, Glaser 1987, Hotes et al. 2001). The plant prefers full sun but can survive in some shade. Shaded individuals growing within *Sphagnum* moss mats do not form rosettes but have long axes (Crowder et al. 1990).

True bogs, which are ombrogenous (rain generated) and ombrotrophic, are hydrologically supported solely by precipitation and receive nutrients largely through wet and dry atmospheric deposition. Consequently, these habitats are oligotrophic with respect to nutrient availability and support species adapted to acidic, 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). Because of the relatively warm and dry climate in Region 2, peatlands form only where sufficient groundwater or surface water maintains saturated soil conditions throughout the summer (Cooper 1996). Thus, no true bogs occur in Region 2. However, *Sphagnum*-dominated fens are found in the region, and these share many floristic elements with ombrotrophic bogs and poor fens, including the occasional presence of *Drosera rotundifolia*.

A broad scale assessment of fens in the Sierra Nevada of California indicated that *Drosera rotundifolia* is much more common there than in

Table 2. Genetic variability at 13 loci of *Drosera rotundifolia* from Colorado and California occurrences, where n = sample size; A = average number of alleles per locus; P = percentage of polymorphic loci; H_o = observed heterozygosity; H_e = expected heterozygosity. Source: Cohu (2004), used with permission.

Occurrence	*n*	A	P	H_o	H_e
Gunnison County, Colorado	30	1.08	0.0	0.08	0.04
Central Colorado	30	1.08	0.0	0.08	0.04
Northern Colorado	30	1.08	0.0	0.08	0.04
California	30	1.08	0.0	0.08	0.04
Purchased plants	30	1.08	0.0	0.23	0.12

Region 2 (Cooper and Wolf unpublished data). In addition, *D. rotundifolia* occurred more frequently in northern and lower elevation California fens that received higher annual precipitation (**Figure 11**). The precipitation distribution of the Sierra Nevada is strongly skewed towards winter snow, with less than 10 percent of the total annual precipitation occurring in summer, a marked contrast to the Rocky Mountains where summer rain may be abundant.

Since *Drosera rotundifolia* is intolerant of desiccation, it survives only in sites with stable groundwater inputs that maintain water tables near the soil surface. Winter snow and summer rain recharge hillslope aquifers, which discharge consistently throughout long, warm summers. The abundance of *D. rotundifolia* occurrences that flourish during the mostly rainless Sierra Nevada summer underscores the species' restriction to sites with constant groundwater discharge.

The four principal landform configurations that produce groundwater discharge systems capable of supporting fens in mountain regions of the western United States are discrete hillslope springs, upwelling springs, closed basins, and 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 12**). Upwelling 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 vertical hydraulic pressure of the emerging water will be held by the entwined mat of roots and peat, forming a spring mound (**Figure 13**). In closed basins where groundwater discharge collects in a lake, floating vegetation mats can form, starting at the lakeshore or on fallen logs and encroaching inward. Fens may grow a short distance up the shore slope if the capillary fringe and/or upslope springs provide sufficient perennial water (**Figure 14**). Finally, fens most commonly form 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 a steady, diffuse discharge that supports fen formation (**Figure 15**). The Jackson County site 1 and Grand County *Drosera rotundifolia* occurrences grow on floating mats in closed basins (**Figure 14**) while the Gunnison County occurrence is located in an open-basin sloping fen (**Figure 15**).

Ellenberg indicator values (IV) are a rating system relating species affinities for particular environmental characteristics such as light, nutrients, and water availability. European ecologists commonly use this approach. In a comprehensive assessment of the British flora, Hill et al. (1999) characterized *Drosera rotundifolia* as an indicator of wet (IV = 9 out of 12) and nitrogen-deficient (IV = 1 out of 9) sites. With regard to pH, *D. rotundifolia* occurred in acid sites, but not exclusively, giving the species an IV of 2 out of 9 for soil reaction (Hill et al. 1999).

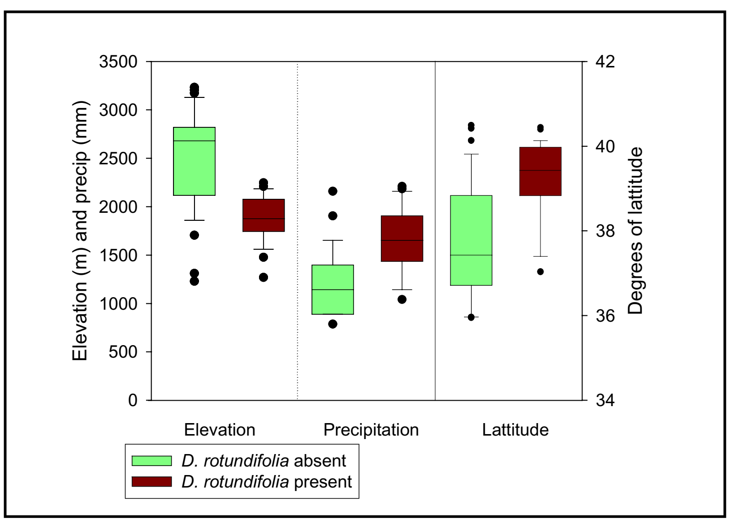

Figure 11. Boxplot comparison of environmental variables in Sierra Nevada fens where *Drosera rotundifolia* was present and absent.

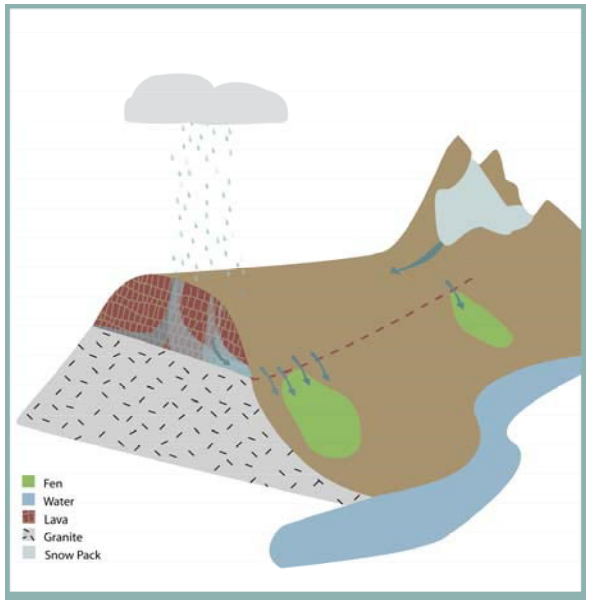

Figure 12. Illustration of hillslope fens associated with a bedrock contact (shown in cutout) or a bedrock fracture (indicated by dashed red line).

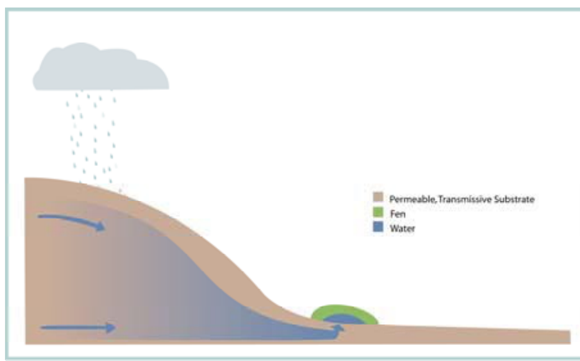

Figure 13. Illustration of upwelling groundwater at the toe of a hillslope supporting a spring mound fen.

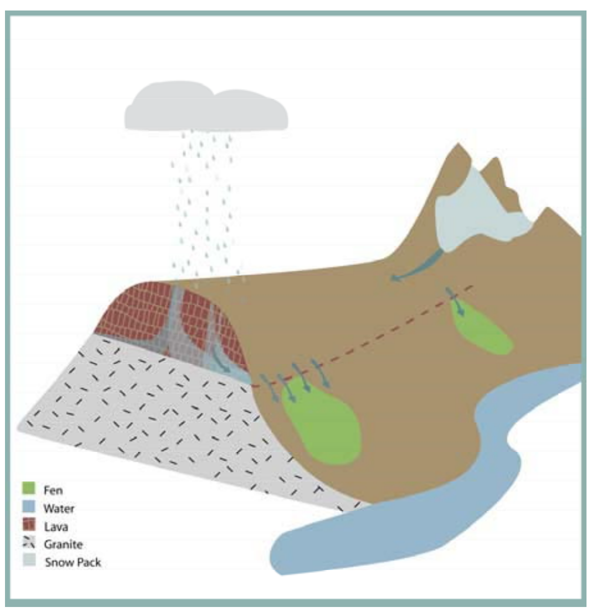

Figure 14. Illustration of a closed basin where groundwater feeds a lake that supports a floating mat fen.

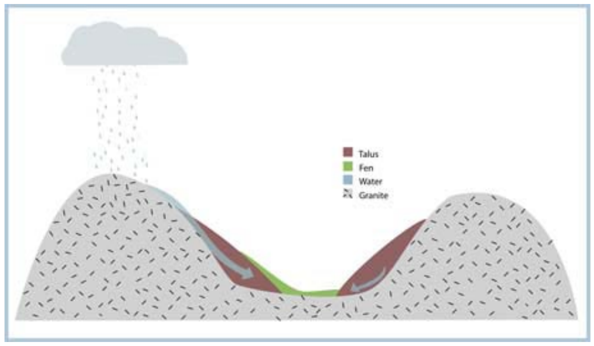

Figure 15. Illustration of sloping fen that formed where groundwater flow is concentrated.

Substrate characteristics and microhabitats

Throughout the world *Drosera rotundifolia* occurs on peat, particularly on living *Sphagnum* moss, but it can occur on floating logs or damp acidic sand near ponds or streams (Swales 1975, Crowder et al. 1990). *Drosera rotundifolia* in Region 2 occurs only on living *Sphagnum* moss and peat generated by *Sphagnum* moss. Moderately productive peat is most favorable because it represents the optimal balance between water supply and overgrowth by associated species, notably *Sphagnum* moss (Nordbakken et al. 2004).

Within individual wetland complexes, *Drosera rotundifolia* has been shown to occur in a range of microhabitats characterized by particular physiochemical and floristic characteristics. For example, in northern Minnesota, which contains extensive and diverse peatlands, *D. rotundifolia* occurs in a variety of habitats including non-forested bogs, poor fen margins, strings, and tree island habitats (Glaser 1987).

Region 2 habitat characteristics

In Region 2, *Drosera rotundifolia* is known from two primary habitat types, sloping iron fens and floating mats around small ponds. Iron fens are rare (~ 10 known) in the region, and only the Gunnison County fen supports *D. rotundifolia*. This iron fen, located on the south slope of a meta-sedimentary mountain in Gunnison County, was the first location where *D. rotundifolia* was found in this region. There has been some speculation that these plants were introduced during the 20th century. However, the discovery of other occurrences in Colorado and the recent work comparing the genetics of *D. rotundifolia* in Colorado and California occurrences (Cohu 2003) have clarified this issue; *D. rotundifolia* is certainly native in Colorado.

A water track in the Gunnison County iron fen contains numerous, small, unvegetated pools, and strings dominated by *Carex aquatilis* and *Sphagnum angustifolium* (**Figure 16**). Small *Drosera rotundifolia* occurrences are found here in areas within a nearly continuous cover of *S. angustifolium* and *S. fimbriatum* (Cooper 2003), which both tolerate and produce strongly acidic waters (Andrus 1986, Crum 1988). While in most fens and bogs the acidic conditions are produced by *Sphagnum* cation exchange capacity or the abundant organic acids, in iron fens, the acids are produced by the oxidation of iron pyrite in the watershed. Thus, iron fens have highly acid (pH 3.0 to 4.0) water sources, and this external source of acids controls site water chemistry.

The other three confirmed Colorado *Drosera rotundifolia* occurrences, Jackson County sites 1 and 2, and Grand County, grow on floating or poorly anchored *Sphagnum* mats on pond margins (**Figure 17**, **Figure 18**). Floating mats rise and fall, with pond water levels maintaining the water table within the mat throughout the year. The floating mat is typically created by *Sphagnum* mosses, as well as the roots of species such as *Carex limosa*, *C. lasiocarpa*, *Menyanthes trifoliata*, and *Comarum palustre*, all of which are rare in Colorado.

Floating mats are highly susceptible to degradation and only develop in small ponds that do not have significant wave action. They are isolated from valley margins and do not directly receive inflowing groundwater. Capillary rise from the pond water saturates floating mats, and their 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 the 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 rotundifolia*.

Figure 16. Photograph of the Gunnison County fen, Gunnison National Forest. Photograph by D. Cooper.

Figure 17. Example of the type of floating mat habitat that supports *Drosera rotundifolia* at the Grand County fen. Photograph by J. Rocchio, used with permission.

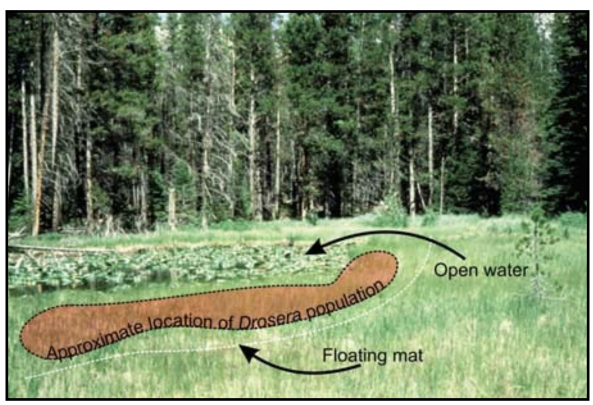

Figure 18. Floating mat at Jackson County site 1. Photograph by B. Neely, used with permission.

Some floating mats are close enough to forest margins that falling trees may reach the mats; these do provide habitat for upland or other wetland plants.

The *Drosera rotundifolia* occurrence at Jackson County site 1 is confined to a small area on raised *Sphagnum* mats. Plants were observed within areas of standing water, as well as at drier sites at the western fen edge. No plants were found in areas of tall *Carex*-dominated vegetation; instead plants are confined to open, sunny locations (Cohu personal communication 2004).

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 upon which fen plants depend 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).

The Gunnison County site provides a key example of the importance of watershed geology on fen water chemistry. This iron fen is one of approximately 10 iron fens known in the southern Rocky Mountains (Cooper 2003). The watershed supporting the fen and its *Drosera rotundifolia* occurrence is composed of pyrite rich bedrock and talus, which, when oxidized, forms sulfuric acid. Surface water and groundwater flowing into the fen from the upslope watershed have exceptionally low pH values for Region 2 fens (**Figure 19**). Groundwater and surface water in the vicinity of the *D. rotundifolia* occurrences have a pH of approximately 3.2 to 3.9 (**Figure 19**). In contrast, groundwater discharging upward from a shale rich lateral glacial moraine on which the fen sits has a pH >6.0, demonstrating the complex interaction of multiple surface and groundwater sources that may occur in fens.

At the Gunnison County fen, the acid water dissolves soluble metals, thus making the water ion rich. Although iron fens may be high in certain cations, they are still very nutrient poor with respect to the major elements required by plants (i.e., nitrogen, phosphorus, potassium).

While bogs and poor fens have acidic waters, their water supply is primarily or solely rainwater, which has low concentrations of ions. In addition, the acids in bogs and poor fens are produced during cation exchange by *Sphagnum* mosses (Cooper et al. 2002). However, bogs and poor fens support many of the same acidic water- and soil-tolerant plant species as iron fens, including *S. fuscum*, *S. angustifolium*, *S. russowii*, *S. fimbriatum*, *Carex aquatilis*, *C. utriculata*, *Betula glandulosa*, *Drosera rotundifolia*, *Vaccinium scoparium*, *Calamagrostis canadensis*, *Pinus contorta*, and *Picea engelmannii* (Cooper 2003).

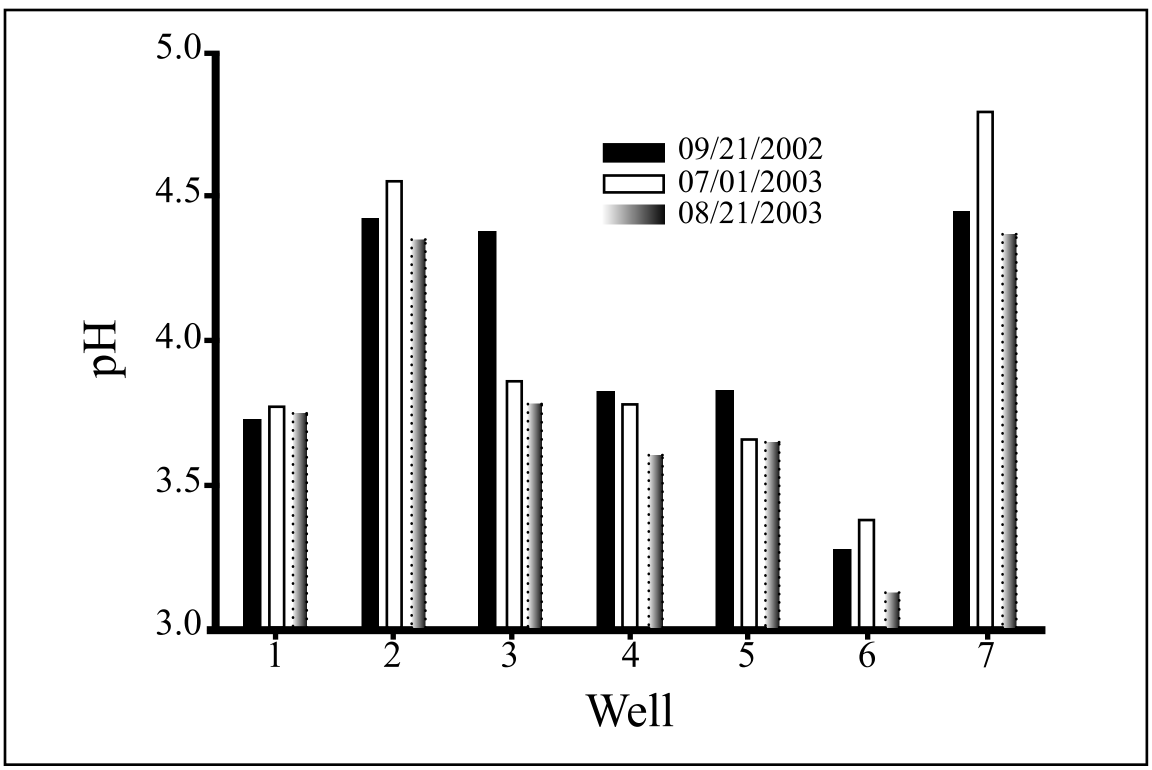

Figure 19. pH values from groundwater monitoring wells established across the fen in Gunnison County. *Drosera rotundifolia* occurrences are concentrated near wells 3 and 5. Source: Cooper (2003), used with permission.

Water chemistry data from elsewhere in the world indicate that *Drosera rotundifolia* favors acidic and low nutrient habitats, but there are exceptions (**Table 3**). 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). Cation concentrations were generally low in fens supporting *D. rotundifolia* occurrences in California, but there was considerable variability (**Figure 20**). Fens in California without *D. rotundifolia* were similarly variable and generally low in cation concentrations (Cooper and Wolf unpublished data).

Wetland hydrology

In nutrient-poor peatlands, the water table gradient is by far the most important internal 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). More than 80 percent of *Drosera rotundifolia* plants were found where the median water table depth was 8.9 cm (range = 3 to 15 cm), and the plants preferred sites towards the high end of the peat productivity gradient (Nordbakken et al. 2004). A study of a weakly minerotrophic montane fen in the southern Alps also demonstrated a strong correlation between water table depth and the presence of *D. rotundifolia* (**Figure 21**; Bragazza and Gerdol 1996). They only found *D. rotundifolia* along a relatively narrow range of water table depths, from 0 to 24 cm, while the species was present along a wide range of pH values.

Drosera rotundifolia individuals can survive complete inundation for several weeks (Crowder et al. 1990), but they do not grow in sites with perennial standing water. Germination and growth generally start while the peatland surface is covered by melt water in the spring. 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.

Table 3. Comparison of water pH, calcium (Ca^{2+}) and magnesium (Mg^{2+}) ion concentrations (mg/L) measured in wetlands with *Drosera rotundifolia*.

Study location	Source	pH	Ca^{2+}	Mg^{2+}
Region 2 (Colorado)				
Grand County	Rocchio and Stevens 2004	5.6-6.8	Not available	Not available
Gunnison County	Cooper 2003	3.6-4.4	13.5-27.3	3.5-7.3
North America				
Maine	Anderson and Davis 1997	4.3	0.6	0.02
Alberta	Chee and Vitt 1989	5.3-7.1	19.5-22.1	4.3-5.3
Labrador	Wells 1996	3.9-5.0	1.8-6.0	Not available
California	Cooper and Wolf unpublished data	5.0-7.4	1.0-35.4	0.1-16.7
Wisconsin	Frolik 1941	4.5-7.0	Not available	Not available
Minnesota	Glaser et al. 1990	4.6-5.3	3.0	Not available
New York	Motzkin 1994	6.5	22	Not available
Ontario	Sjors 1963	4.1-5.4	2.0	0.5
Alberta	Szumigalski and Bayley 1997	5.68-6.57	8.0-22.5	3.6-6.6
Alberta	Szumigalski and Bayley 1997	7.8-8.4	57.8-114.5	21.4-39.9
Alberta	Vitt et al. 1975	5.2	2.3	0.4
Europe				
Sweden	Hanslin and Karlsson 1996	4.6	Not available	Not available
England	Crowder et al. 1990	3.5-6.6	1.2-22	1.2-5.0
England	Haslam 1965	6-7.5	30 (30-39)	Not available
Netherlands	Wassen and Barendregt 1992	5.5-6.5	16 (7-25)	Not available
Sweden	Gunnarsson et al. 2002	3.9-4.9	Not available	Not available

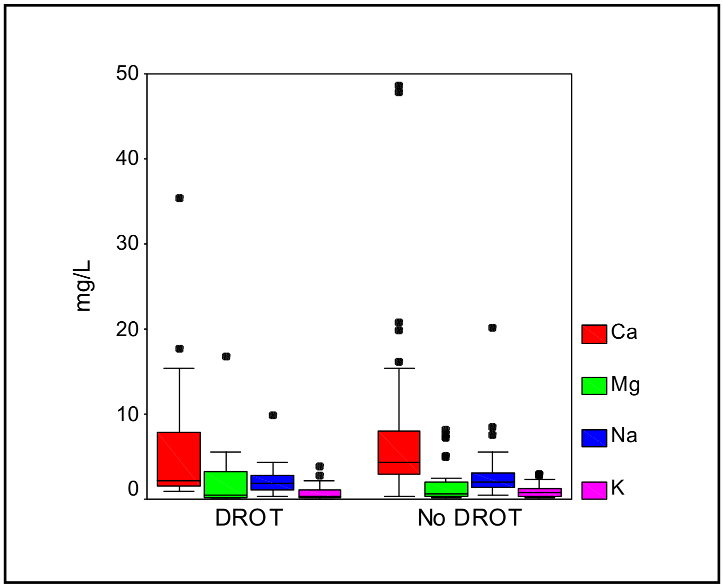

Figure 20. Box plots of water chemistry parameters comparing Sierra Nevada fens with *Drosera rotundifolia* (number of locations, n = 22) and without *D. rotundifolia* (n = 39). Source: Cooper and Wolf unpublished data, used with permission.

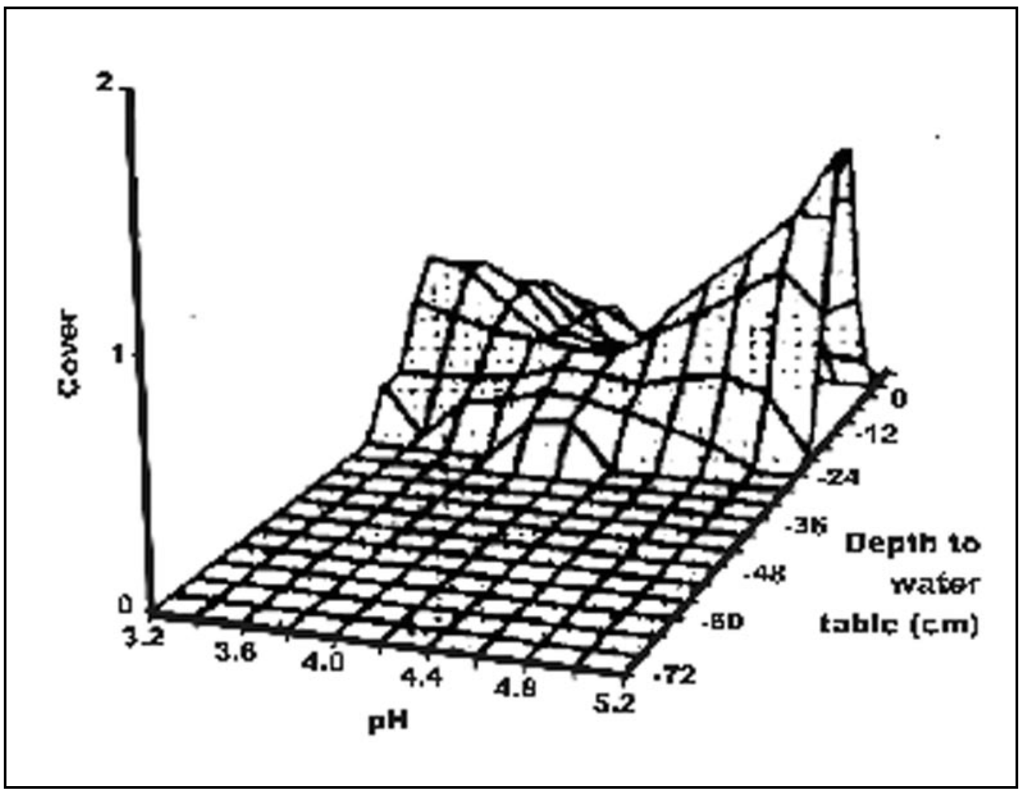

Figure 21. Response surface for *Drosera rotundifolia* along water table and pH gradients in an Italian poor fen. Values on the vertical scale indicate predicted cover along a 10-point scale, calculated using observed cover value. Source: Bragazza and Gerdol (1996), used with permission.

A similar hydrologic environment is present at the Gunnison County fen. At this site, the water table is near the surface throughout the growing season and exhibits small annual variation (**Figure 22**). Although no hydrologic data are available for the other Region 2 occurrences, they all occur on floating peat mats, and so presumably water tables are consistently near the soil surface.

Vegetation associations and associated plant species

Species composition of floating mats varies but typically includes *Sphagnum* mosses (principally *S. squarrosum*, *S. teres*, and *S. fimbriatum*), sedges (e.g., *Carex limosa*, *C. lasiocarpa*), and herbaceous dicots (e.g., *Menyanthes trifoliata*, *Comarum palustre*). Dominant species at the fen in Grand County include *Carex lasiocarpa*, *Sphagnum* spp., *Comarum palustris*, *Carex interior*, *C. buxbaumii*, and *C. magellanica* (Rocchio and Stevens 2004).

Although typically associated with acidic wetland types such as bogs and poor fens, *Drosera rotundifolia* has been documented in rich fens as well. For example, Motzkin (1994) found *D. rotundifolia* in a calcareous fen associated with *Carex lasiocarpa*, *Myrica gale*, *Potentilla fruticosa, Peltandra virginica, and Cladium mariscoides.* Dominant bryophytes included *Campylium stellatum, Calliergonella* spp., and *Sphagnum* spp. Species in wetlands supporting *D. rotundifolia* occurrences are listed in **Table 4**, but it should be noted that some species might not occur in microsites with *D. rotundifolia*.

Competitors and relationship to habitat

In peatlands, where *Drosera rotundifolia* occurs with *Sphagnum* moss, competition for sunlight can significantly affect the size and distribution of *D. rotundifolia* plants. While the small size of *D. rotundifolia* plants reduces their demand for resources, it also makes them particularly sensitive to drought and burial by *Sphagnum* growth (Nordbakken et al. 2004). *Drosera rotundifolia* can tolerate some shading but does not survive in dense shade (Crowder et al. 1990).

The encroachment of *Alnus* spp. (alder) and *Frangula alnus* (alder buckthorn) shrubs (63 to 100 percent canopy coverage) decreased sunlight reaching a Croatian fen and caused a shift from *Rhynchospora alba* and *Drosera rotundifolia* dominance to *Sphagnum subsecundum* and *Molinia caerulea* (Hrsak 1996). Although *A. incana* ssp. *tenuifolia* (alder) are common in Region 2, they are rarely associated with the fen types supporting *D. rotundifolia* (Cooper personal observation).

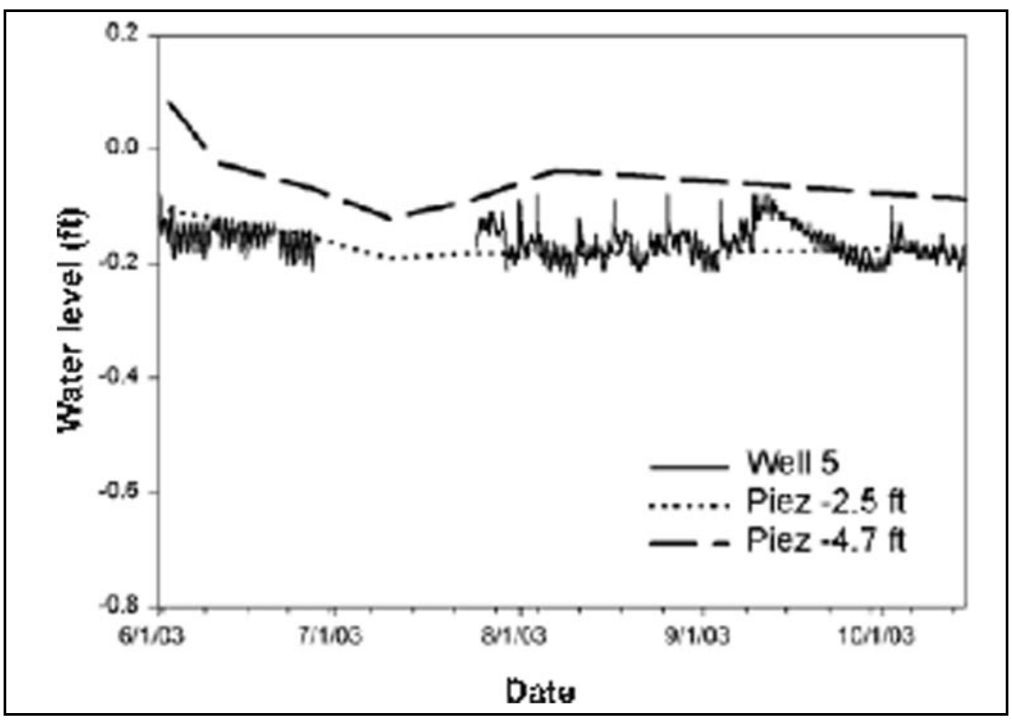

Figure 22. Monitoring well and piezometer data from well 5 in the Gunnison County fen, demonstrating the stable water table and influence of groundwater on fen hydrology. Source: Cooper (2003), used with permission.

Table 4. Common vegetation associates reported from wetlands supporting *Drosera rotundifolia*.

Study location	Source	Associated species
Region 2 (Colorado)		
Gunnison County	Cooper 2003	*Sphagnum angustifolium*, *S. fuscum*, *S. russowii*, *S. fimbriatum*, *Carex aquatilis*, *C. utriculata*, *C. viridis*, *Betula glandulosa*, *Vaccinium scoparium*, *Calamagrostis canadensis*, *Eriophorum angustifolium*, *Pinus contorta*, *Picea engelmannii.*
Grand County	Rocchio and Stevens 2004	*Carex lasiocarpa*, *Comarum palustre*, *Carex vesicaria*, *Sphagnum* spp.
North America		
New Hampshire	Atkinson 1984	*Eriophorum angustifolium*, *Narthecum ossifragum*, *Sphagnum papillosum*
California	Engelhardt 1998	*Sphagnum fuscum*, *Drosera anglica*
Wisconsin	Frolik 1941	*Menyanthes trifoliata*, *Kalmia polifolia*, *Vaccinium* spp., *Sarracenia purpurea*, *Eriophorum virginicum*, *Andromeda glaucophylla*, *Chamaedaphne calyculata*
Minnesota	Glaser et al. 1990	*Scirpus hudsonianus*, *Cladium mariscoides*, *Parnassia palustris*, *Menyanthes trifoliata*, *Muhlenbergia glomerata*, *Scirpus cespitosus*, *Carex lasiocarpa*, *Drosera anglica*, *D. intermedia*, *Carex livida*, *Utricularia intermedia*
New York	Motzkin 1994	*Carex lasiocarpa*, *Cladium mariscoides*, *Sarracenia purpurea*, *Vaccinium macrocarpon*, *Menyanthes trifoliata*, *Campylium stellatum*
Alberta	Szumigalski and Bayley 1997	*Scirpus cespitosus*, *Scorpidium scorpioides*, *Drepanocladus revolvens*, *Tomenthypnum nitens*
Europe		
Sweden	Foster and Fritz 1987	*Carex rostrata*, *Scirpus cespitosus*, *Eriophorum angustifolium*, *Pinus sylvestris*
Sweden	Hanslin and Karlsson 1996	*Sphagnum* spp., *Rubus chamaemorus*, *Betula nana*, *Vaccinium microcarpum*, *Empetrum hermaphroditum*, *Andromeda polifolia*
England	Haslam 1965	*Schoenus nigricans*, *Carex elata*, *Betula* spp., *Cladium mariscus*, *Epipactis palustris*
Netherlands	Wassen and Barendregt 1992	*Carex echinita*, *Carex lasiocarpa*, *Potentilla erecta*, *Eriophorum angustifolium*, *Sphagnum magellanicum*, *Sphagnum palustre*
England	Wheeler 1980	*Juncus actiflorus*, *Pedicularis sylvatica*, *Serratula tinctoria*, *Calypogeia fissa*, *Cephalozia bicuspidata*, *Dicranella heteromalla*, *Lepidozia setacea*, *Pohlia nutans. Erica tetralix*, *Nordus stricta*, *Calluma vulgaris*, *Aulacomnium palustre*, *Calluna vulgaris*, *Erica tetralix*

Competition for growth-limiting mineral nutrients in *Sphagnum* peatlands strongly influences community structure and species diversity. When fertilized, *S. fuscum* responded by an increase in the height of its green parts. *Drosera rotundifolia* also responded to *S. fuscum* fertilization with an increase in height of the vertical stem that connects the leaf rosettes of two successive years' growth. Thus, *D. rotundifolia* avoided being overgrown and shaded by matching *Sphagnum*'s vertical growth (Svensson 1995).

The ability of *Drosera rotundifolia* to capture and retain insects leads to competition for critical nutrients within occurrences and between carnivorous plants and insect predators. In addition to the competition between *D. rotundifolia* plants for limited insect resources (Gibson 1991), ants have been observed robbing food from the leaves of *D. rotundifolia*. In one study, only 29 percent of added flies remained on *D. rotundifolia* leaves for more than 24 hours (Thum 1989b). Ants showed higher activity in the warmer, sunnier, and elevated microhabitat of *D. rotundifolia* compared to that of *D. intermedia*. Larger plants were better than smaller ones in retaining added flies. The advantage of plundering appears to be greater for the ants than the danger of being caught. The prey collected from

D. rotundifolia may be an important source of food for peatland-dwelling ants (Thum 1989b).

Herbivores and relationship to habitat

There are few studies of herbivory on *Drosera*, and none specific to *D. rotundifolia* in Region 2. In an occurrence of *D. capillaris* in Florida, caterpillars of a plume moth (*Trichoptilus parvulus*) have been found feeding on the leaf blades, glands, and dead insects trapped by the plant (Eisner and Shepherd 1965). However, it is unlikely that invertebrates specialize in consuming *D. rotundifolia* since occurrences are localized and productivity of plants and occurrences is low. However, generalist herbivores may opportunistically utilize the plant. *Drosera rotundifolia* is commonly eaten by moose on the Kenai Peninsula of Alaska in late May and June when it is in its preflowering 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 the same as *A. trichoglochinis* Theobald), is known to infest *Drosera rotundifolia* and was described as a pest in the Netherlands. Whether this aphid 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 large distance between Region 2 *D. rotundifolia* occurrences 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 rotundifolia* and other organisms, except for a reference to mycorrhizal fungi (see above). 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).

CONSERVATION

Threats

Historically, many peatlands in 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). In addition to these 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 peatland abundance and distribution – the wetland type critical for *Drosera rotundifolia*.

Direct hydrologic alteration, such as dewatering through ditching, fundamentally changes the ecological properties of impacted wetlands and reduces their suitability for obligate wetland species such as *Drosera rotundifolia*. Consequently, direct hydrologic alteration represents the single greatest historic and current threat to *D. rotundifolia* 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-dependent 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, which is susceptible to subsequent loss through evaporation or sublimation (Kauffman et al. 1997). Thus, any natural or anthropogenic process that significantly alters upland vegetation, for example fire or timber harvest, can 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 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 potentially produce negative effects on fen vegetation.

Increased water yield from upland portions of peatland watersheds could generate wetter conditions, perennially flooding microsites required by *Drosera rotundifolia*. 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 the removal of upland vegetation could increase mineral sediment fluxes to fens and therefore negatively impact peat formation, nutrient dynamics, and water table depths, any of which could affect *D. rotundifolia*.

Most water derived from snowmelt passes through subalpine watersheds not as surface flow, but rather 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 effects of these changes in surface and subsurface flows on peat chemistry and the consequential potential effects on wetland flora are unknown.

Fire

The indirect effects of fire occurring in uplands adjacent to fens supporting *Drosera rotundifolia* 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. rotundifolia* 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 (Schnell 2002). Although there are few data available for soil temperature and fire duration mortality thresholds for *Drosera rotundifolia*, the species has been characterized as tolerant of and even opportunistically dependent on low-temperature fires; it 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 (Cooper and Van Haveren 1994, Sherriff et al. 2001), suggesting that fire has had, at most, an episodic role in the population dynamics of the region's *Drosera rotundifolia* occurrences.

Significant departure from historic mean fire return interval could lead to a degradation of *Drosera rotundifolia* 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 the 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. rotundifolia* 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. rotundifolia*.

Roads and trails

Roads, and to a lesser degree, trail networks can have significant effects on local and watershed-scale hydrologic processes, and can therefore have indirect impacts on fens supporting *Drosera rotundifolia* 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 deicing agents, magnesium chloride, or other dust abatement chemicals (Wilcox 1986, Trombulak and Frissell 2000). Since the road density near Region 2 *Drosera rotundifolia* occurrences is relatively low, these impacts likely represent a minor threat to these occurrences, but 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. rotundifolia*.

Because most Region 2 *Drosera rotundifolia* 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 on *D. rotundifolia* may be modest. More significant, perhaps, is the increased possibility of a denser road network intercepting and diverting spring discharge that feeds into fens.

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 which have been altered hydrologically (Wilcox 1995). However, even in disturbed wetlands, weeds have not been observed in the wet and acidic microsites supporting *Drosera rotundifolia* 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. rotundifolia* occurrences by collectors.

Although USFS regulations prohibit driving in peatlands, damage from off-highway vehicles (OHVs) has been documented. An example is the September 2000 "mudfest" near the Roosevelt National Forest in Colorado, where several hundred OHVs 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). Though certainly a factor contributing to the degradation of some fens, there is no evidence to suggest a direct threat to Region 2 *Drosera rotundifolia* occurrences from OHV use. However, even a single OHV could cause significant damage if driven directly onto a *D. rotundifolia* occurrence.

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 (World Energy Council 2004).

Sites possessing the necessary hydrologic conditions for peat accumulation are fairly 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 2005).

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 are within the three counties that have *Drosera rotundifolia* occurrences (Colorado Division of Minerals and Geology 2006).

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* occurrences in the region. However, the recent rise in oil prices has fueled a shift in the focus of national and local energy policy towards other sources of energy. If the new focus were to include peat and if peat mining were to resume, it would represent a serious threat to *D. rotundifolia*.

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 rotundifolia* occurrences, with the likely exception of the Gunnison County fen population. Areas upslope of the fen have been mined, and more extensive molybdenum deposits are known to occur. The inflow of acidic groundwater critical to maintaining the low pH required by *D. rotundifolia* and other rare acidiphiles such as *Sphagnum balticum* could be reduced if large-scale mining resumes, and this could cause a shift in the fen's hydrogeochemical balance towards the less acidic groundwater discharged from the underlying lateral moraine (**Figure 23**; Cooper et al. 2002, Cooper 2003).

Livestock and native ungulate grazing

The effects of livestock grazing on *Drosera rotundifolia*, at both the individual and community levels, are largely unknown. *Drosera rotundifolia* has been shown to respond positively 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. rotundifolia* occurrences are perennially wet, livestock may use them somewhat less. However, even modest livestock use can punch holes through the floating mat and destroy the root and rhizome systems of plants that form it. Since floating mat plants are all slow growing, this can expose soils to oxidation and result in peat loss.

Native ungulates can also have significant effects on wetlands and possibly impact *Drosera rotundifolia* occurrences. Moose and/or elk trampling was also noted at the Grand County fen, and local levels of ungulate use appear higher than historic use, based on observations of willow browse patterns (Popovich personal communication 2004).

Recreational impacts

Recreational impacts to fens are typically due to trampling. Users include fisherman, native plant enthusiasts, and hikers that come to the edge of floating mats to enjoy the open views, reflections, unusual colors, and to attempt fishing. The Grand County fen was recently acquired by the Arapaho National Forest and opened to recreational use. A rapid increase in visitor traffic has occurred since this fen was written up in an area hiking guide, and this has led to severe trampling in areas that support a large *Drosera rotundifolia* occurrence (**Figure 24**; Cooper personal observation).

Visitation from hikers and campers has also been identified as a potential threat for the Jackson County site 1 occurrence (Proctor personal communication 2004). The area supporting *Drosera rotundifolia* occurs

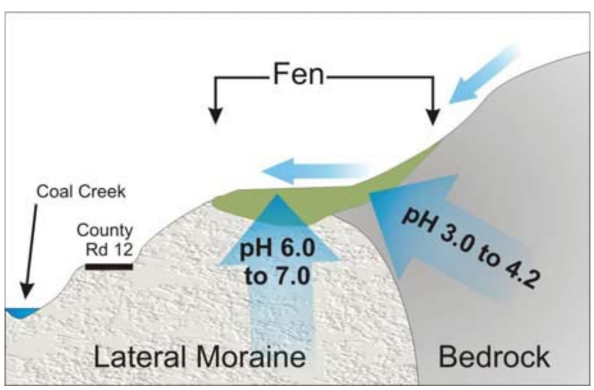

Figure 23. Schematic cross-section of the Gunnison County fen supporting *Drosera rotundifolia*. Groundwater discharging into the fen from the bedrock of the meta-sedimentary mountain to the north (right side of the figure) is strongly acidic. However, the fen has formed upon a lateral moraine composed of circumnuetral and alkaline till derived from the West Elk Mountains, from which it receives inputs of groundwater with high pH. Since *D. rotundifolia* appears to be limited to the sites with low pH, any significant hydrologic alterations reducing the influx of acidic groundwater from the meta-sedimentary mountain, such as mining of known molybdenum deposits, could drastically alter the suitability of the site for the species.

Figure 24. Effects of trampling from recreational users on the floating mat of the fen in Grand County. Steve Popovich, botanist for the Araphaho-Roosevelt National Forest is looking at the brown, exposed peat. (Photograph by D. Cooper, September 3, 2004, used with permission).

within 20 m of a frequently used hiking trail and is less than ½ km from a developed campground, making access particularly easy.

The Gunnison County fen receives moderately high recreational and educational use from locals, researchers, and tourists (Cooper personal observation).

There are no documented impacts on *Drosera rotundifolia* 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 and Arapaho national forests (Popovich and Proctor personal communication 2004).

Over-collection

Human use of *Drosera* species for medicinal purposes has a long and interesting history. The 'perpetual dew' of sundews has long 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 *D. rotundifolia* as a diuretic, a laxative, and a treatment for a variety of kidney, stomach, and liver problems. The potential value of *D. rotundifolia* as an herbal remedy may create an incentive for collection, particularly as commercial markets exist for *D. rotundifolia* tinctures and compounds. Although no documented occurrences of collections for this purpose are known from Region 2, the limited distribution and abundance of *D. rotundifolia* 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. The Colorado occurrences of *D. rotundifolia* are small enough that they could be over-collected in a single harvest visit.

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

Exotic species

Although exotic species are generally recognized as one of the principle threats to the integrity of ecological systems (Mack et al. 2000, Crooks 2002), there is no evidence to suggest that *Drosera rotundifolia* is directly threatened by exotic species within Region 2. None of the state or county-listed noxious weed species listed in Colorado are noted in habitat descriptions of known occurrences (Cooper 2003, Rocchio and Stevens 2004). Although exotics such as Canada thistle (*Cirsium arvensis*) may invade fens (Blumenthal and Jordan 2001), this is typically associated with hydrologic alterations such as ditching. In addition, the iron fen and floating mat environments supporting Region 2 *D. rotundifolia* occurrences do not appear conducive to weed invasion.

Atmospheric deposition of pollutants

In nutrient-poor environments, *Drosera rotundifolia* 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), and as a consequence, it may be vulnerable to the increased deposition of airborne nitrogen observed in portions of Region 2 (Svensson 1995). A wide variety of ecological responses have 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 those in surface waters east of the Divide. However, elevated amounts of atmospheric nitrogen deposition have been observed in the Mt. Zirkel Wilderness on the Routt National Forest, which is near several *D. rotundifolia* occurrences (Burns 2002).

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 have profound effects on the structure and function of the wetlands supporting *Drosera rotundifolia*. 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 feedback 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 rotundifolia* 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. rotundifolia* occurrences by shifting the delicate balance between *D. rotundifolia* 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 greater competition between *D. rotundifolia* and associated vegetation.

Ultimately, the most important climatic factor influencing the future of peatlands in the region is likely to be the spatial and temporal patterns of future precipitation (Moore 2002). Because of the region's climate, areas capable of accumulating peat are rare on the landscape and rates of peat formation are slow, approximately 20 cm per 1000 years (Chimner et al. 2002, Chimner and Cooper 2003). The disjunct nature of Region 2 *Drosera rotundifolia* occurrences, widely separated from other occurrences and suitable habitats, suggests that the fate of the species in the region is intimately tied to that of the wetlands presently supporting it – the conclusion reached for other rare fen species in the region (Cooper 1991).

Assessment of threats to Region 2 *Drosera rotundifolia* populations

In **Table 5**, we present a qualitative assessment of the importance of different threats to known Region 2 *Drosera rotundifolia* populations. Unfortunately, few data are available from which to confidently make these evaluations. Assessments should therefore be viewed as initial hypotheses in need of more research.

Conservation Status of Drosera rotundifolia in Region 2

Drosera rotundifolia has been given sensitive status in Region 2 principally because of its rarity and

Table 5. Estimates of the relative importance of various threats to USDA Forest Service Region 2 *Drosera rotundifolia* occurrences. The map key corresponds to occurrences presented in Figure 5. The significance of threats are qualitatively assessed as either high (H - threat imminent or ongoing), intermediate (I - not imminent or ongoing, but significant chance of future impact), or low (L - no apparent present impact, small likelihood of future threat). Question marks are used where there is no information available to make an assessment.

	Threats							
Map key	**Logging/ fire**	**Roads/ trails**	**Mining**	**Grazing**	**Exotic species**	**Direct hydrologic alteration**	**Climate change/ Pollution**	**Recreational impacts**
1	L	I	L	L	L	L	I	I
2	L	I	L	L	L	L	I	I
3	?	?	?	L	?	L	I	I
4	?	?	?	L	?	L	I	I
5	L	H	L	I	L	L	I	H
6	?	?	?	?	?	?	?	?
7	I	I	H	H	L	I	I	H

the sensitivity of its habitat to alteration. However, there are insufficient data available to make conclusive statements regarding trends in the abundance of *D. rotundifolia* within Region 2. Because occurrences are so small and isolated, periodic drought during the Holocene may have led to local extirpation of *D. rotundifolia* occurrences in areas in Region 2 where *D. rotundifolia* 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 becomes a solid peat body dominated by tall *Carex* spp. that can outcompete *D. rotundifolia*.

There is still uncertainty as to the specific origin of Region 2 *Drosera rotundifolia* occurrences. However, the global distribution for *D. rotundifolia* 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 hypothesis, 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 *D. rotundifolia*, this species' distribution is similar to many of the examples he cites, and if his hypothesis is correct, then it is likely that *D. rotundifolia* has been present in the region for far longer than what was suggested by earlier biogeographic theories.

Regardless of their 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. Although diminutive, *D. rotundifolia* are distinctive plants and not likely to be overlooked or misidentified in botanical surveys, as is common for many *Carex* species and bryophytes. However, since no systematic survey of Region 2 fens has been conducted, it is certainly possible that additional undocumented occurrences could be found. The recent discovery of the occurrence in Grand County serves as an example (Rocchio and Stevens 2004). As a consequence, all fens need to be carefully evaluated for the presence of *D. rotundifolia* prior to significant shifts in management.

The primary functional elements of *Drosera rotundifolia*'s habitat 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, forest 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 rotundifolia*. This hydrologic stability leads to stable rates of primary production and decomposition the net results of which 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. rotundifolia* occurrences may be relatively resilient to small to intermediate disturbances in the surrounding landscape.

However, activities within fens that disrupt microsite stability, such as the heavy trampling at the Grand County fen, can have serious impacts on localized *Drosera rotundifolia* 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. rotundifolia* 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* *rotundifolia*. 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 rotundifolia*. Any significant fertilizing effect from a nutrient source would favor more generalist competitors over the carnivorous fen specialist, *D. rotundifolia*.

Management of Drosera rotundifolia in Region 2

Implications and potential conservation elements

First and foremost, maintaining the integrity of the fens supporting Region 2 *Drosera rotundifolia* 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 that result 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 rotundifolia* occurrences is critical. The Gunnison County fen provides a good example. Pollen and peat stratigraphy evidence suggest that the Gunnison County fen is over 8,000 years old (Fall 1997). The unique hydrologic, geochemical, and ecological environment found in this site has served as a refugium for several rare species, including *D. rotundifolia* (Cooper 2003). As discussed in the Threats section of this assessment, the ultimate persistence of these species depends upon maintaining stable inflows of acidic water from the watershed. Any reduction in this water source, as might occur if areas upslope are mined, would likely increase the influence of circumneutral water discharging into the fen, thereby altering the geochemical conditions of the site and decreasing the viability of the habitat for acidophiles (**Figure 23**). Since Region 2 occurrences of *D. rotundifolia* are so isolated from one another, the potential for replenishment of these unique occurrences, if lost, is very low.

In addition to minimizing hydrologic alterations, management actions that result in physical trampling of peatlands that support *Drosera rotundifolia* need to be avoided. For instance, dramatic population declines at the Grand County site between 2003 and 2004, coincident with a steep increase in human use, highlight the importance of maintaining the integrity of peat bodies supporting *D. rotundifolia* occurrences. The potential long-term trend towards greater native ungulate use at the site may also threaten the integrity of floating mats supporting *D. rotundifolia*. Though the relative importance of human foot traffic, ungulate use, and interannual climate variation is not known, foot and hoof prints are clearly having an impact on the site.

Tools and practices

Field checking of unverified *Drosera rotundifolia* 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. rotundifolia* as a sensitive species. Designation of the fens that support *D. rotundifolia* 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 rotundifolia* 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 or rerouting trails that are producing qualitative impacts to the *D. rotundifolia* occurrences at present may help to reduce damage from trampling and collecting. 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 *D. rotundifolia* 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. rotundifolia* 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 rotundifolia* 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. rotundifolia* 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. Unfortunately, few studies have identified suitable plant propagation and establishment approaches for peatland species, and apparently none for *Drosera rotundifolia*.

Information Needs and Research Priorities

All *Drosera rotundifolia* 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 at the present. As a consequence, there may be yet more occurrences awaiting discovery. A broad regional inventory of fens would be of great value, increasing our understanding of *D. rotundifolia*'s distribution and conservation status. Since fens support a large number of rare species in addition to *D. rotundifolia*, such a broad-scale effort would also significantly benefit our overall understanding of biodiversity in the region.

Remote sensing data, such as color infrared and natural color 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 could be useful for stratifying wetlands on the basis of their hydrology and vegetation. The floating mats characteristic of the majority of Region 2 *Drosera rotundifolia* occurrences exhibit distinct spectral signatures and could be readily identified for field inventory.

Since most existing records lack data regarding population size, comprehensive demographic surveys of known occurrences need to be conducted in order to better evaluate the current status of *Drosera rotundifolia* occurrences and to provide baseline data critical for future monitoring efforts. Previously surveyed occurrences need to be periodically monitored in order to identify potential trends in abundance and distribution.

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), quantitative methods of estimating occurrences are far more reliable for developing initial population estimates and for estimating population trends. Although *Drosera rotundifolia* is easily identified anytime during the growing season, monitoring visits timed to coincide with flowering and fruiting 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 *Drosera rotundifolia*. Of particular importance are hydrologic and geochemical characterizations of sites that are known to support the species. 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. rotundifolia* occurrences is also important since 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 conservation strategies. Each of the fens supporting Region 2 occurrences has a unique developmental history driven in large part by their specific hydrogeochemical and climatic setting. Although preliminary studies indicate that Region 2 occurrences are extremely similar genetically (Cohu 2003), it is still 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 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 need to be assessed at multiple spatial scales.

Since heavy foot traffic occurs at the Grand County fen, a long-term analysis is needed to determine the effects of trampling on *Drosera rotundifolia*. This would include an annual census and an analysis of the soil seed bank. It is critical to understand the characteristics of *D. rotundifolia* seed production, dispersal, and storage in soils, and how trampling influences these processes.

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 (e.g., *adventitious roots*).

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

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

Anoxia – a pathological deficiency of oxygen.

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.

Calyx – the collective term for sepals.

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 (e.g., fruit, anther, sporangium) to release its contents.

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 minerotrophic peatland (i.e., one deriving water and nutrients from groundwater that has been in contact with mineral substrate); typically more basic and contain more cations than bogs.

Fugacious – withering or dropping off early.

G1/S1 ranking – critically imperiled globally or subnationally 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 2004).

G2/S2 ranking – imperiled globally or subnationally because of rarity (6 to 20 occurrences) or because of factors demonstrably making a species vulnerable to extinction (NatureServe 2004).

G3/S3 ranking – vulnerable globally or subnationally 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 2004).

G4/S4 ranking – apparently secure globally or subnationally, though it may be quite rare in parts of its range, especially at the periphery (NatureServe 2004).

G5/S5 ranking – demonstrably secure globally or subnationally, though it may be quite rare in parts of its range, especially at the periphery.

Glabrous – lacking hairs, trichomes, or glands; smooth.

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

Herbaceous – plant lacking an aboveground persistent woody stem.

Hibernacula – dormant, overwintering, (hibernating) leaf buds of *Drosera rotundifolia*.

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.

Holotype – the single specimen designated as the type of a species by the original author at the time the species name and description was published.

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.

Iron fens – fens characterized by acidic, iron-rich water that is derived from groundwater sources in contact with iron pyrite-rich rock.

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 involved in a symbiotic association with plant roots.

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.

Oceania – the islands of the southern, western, and central Pacific Ocean, including Melanesia, Micronesia, and Polynesia. The term is sometimes extended to encompass Australia, New Zealand, and the Malay Archipelago.

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 to 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 new size or age class.

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

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

Sensitive species – species of concern designated by the USDA Forest Service due to downward trends in population numbers, density, or habitat capability.

Sepals – a segment of the calyx.

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

Spatulate – spoon-shaped.

Stamen – the pollen-producing organs of a flower.

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 the base of cliffs, or steep slopes.

Tentacular – of, relating to, or resembling tentacles

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

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

Water track – a zone in which minerotropic water is channeled across the body of a peatland.

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