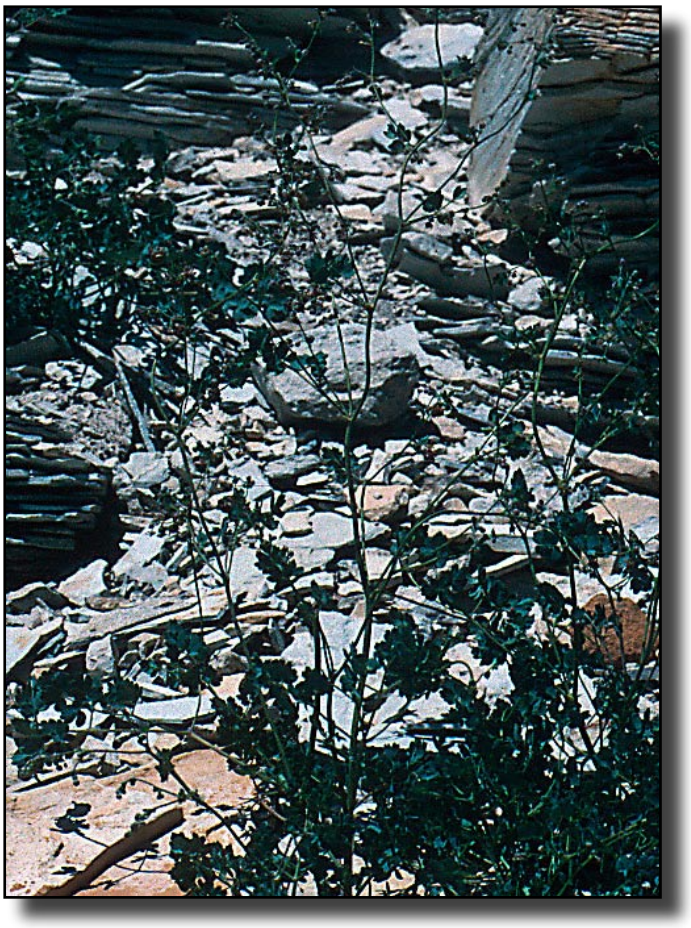
Thalictrum heliophilum Wilken & DeMott (Cathedral Bluff meadow-rue): A Technical Conservation Assessment



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

January 4, 2007

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Peer Review Administered by
Society for Conservation Biology

Panjabi, S.S. and D.G. Anderson. (2007, January 4). *Thalictrum heliophilum* Wilken & DeMott (Cathedral Bluff meadow-rue): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/thalictrumheliophilum.pdf [date of access].

Acknowledgments

This research was facilitated by the helpfulness and generosity of many experts, particularly Carla Scheck, Peggy Lyon, Renee Rondeau, Barry Johnston, and Tamara Meagley. Their interest in the project and time spent answering questions were extremely valuable and their insights into the distribution, habitat, and ecology of *Thalictrum heliophilum* were crucial to this project. Thanks also to Greg Hayward, Gary Patton, Kathy Roche, and Joy Bartlett for assisting with questions and project management. Thanks to Kimberly Nguyen for the work on the layout and for bringing this assessment to Web publication. Mary Olivas provided crucial financial oversight. Annette Miller provided information for the report on seed storage status. Drs. Ron Hartman and Ernie Nelson provided access to specimens of *T. heliophilum* at the Rocky Mountain Herbarium, and Jennifer Ackerfield provided access to specimens from the Colorado State University Herbarium. Nan Lederer and Tim Hogan provided valuable assistance and insights at the Colorado University Herbarium. Jessica Andersen assisted with data and literature acquisition. Special thanks to Karin Decker and Arvind Panjabi who reviewed part or all of the first draft of this document and offered input. Thanks also to Jen Krafchick, Cleome Anderson, Melia Anderson, Arvind Panjabi, Cameron Panjabi, and Donovan Panjabi for their support during the synthesis of this document.

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Cover Photo Credit

Thalictrum heliophilum (Cathedral Bluff meadow-rue). Photograph by Susan Spackman Panjabi.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF *THALICTRUM HELIOPHILUM*

Status

Thalictrum heliophilum Wilken & DeMott (Cathedral Bluff meadow-rue) is a narrowly endemic vascular plant whose global distribution is limited to an approximately 32 by 40 mile (52 by 64 km) area in the Colorado River drainage in northwestern Colorado. Found in dry shale barren communities between 6,200 and 8,800 ft. (1890 and 2682 m) elevation, this species is known from 18 occurrences in three counties. The global population is estimated to be fewer than 200,000 plants within 2,000 acres (roughly 3 square miles) of occupied habitat. Although it is likely that more occurrences will be found by additional inventories, it is not likely that the species will be found to be common, even within its narrow range.

When we began writing this assessment, *Thalictrum heliophilum* was ranked globally vulnerable (G3) by NatureServe and the Colorado Natural Heritage Program. This study provided us with the information to support a rank change to globally imperiled (G2). Region 2 of the USDA Forest Service has designated *T. heliophilum* a sensitive species, but only one of the 18 known occurrences is located on National Forest System land. *Thalictrum heliophilum* is also found on lands managed by the Bureau of Land Management (BLM) and the Department of Energy, and on private lands, but it is not included on the BLM Colorado State Sensitive Species List, nor is it listed as threatened or endangered under the Federal Endangered Species Act.

Primary Threats

There are several threats to the persistence of *Thalictrum heliophilum*, including oil shale mining, oil and gas development, exotic plant species invasions, small population size, grazing and trampling by wild ungulates, and climate change. This species is restricted to substrates that contain high quality oil shale and are underlain by rich deposits of oil and natural gas. Twelve of the 18 known *T. heliophilum* occurrences are on private land, mostly owned by large oil companies (e.g., UNOCAL, Exxon, Occidental Oil, Getty Oil, Texaco Oil, Mobil Oil). Oil and gas development is increasing dramatically within the range of *T. heliophilum*. Oil shale development is happening on a small scale within the range of *T. heliophilum* and is likely to increase in the near future. Weed invasions are also evident in this species' habitat. The primary threat to *T. heliophilum* on National Forest System land appears to be browsing and trampling by wild ungulates.

Primary Conservation Elements, Management Implications and Considerations

Research is needed to understand the threats to *Thalictrum heliophilum*, and threat mitigation is needed to ensure that no occurrences are lost. Additional species inventories are a high priority for this species and are likely to identify new occurrences. A landscape-level approach to conservation of *T. heliophilum* is not likely to be effective given its tiny global range, specific habitat requirements, and small number of occurrences. Although *T. heliophilum* habitat is steep and highly erosive, plants are rhizomatous and well suited to withstand natural disturbance. Research is needed to investigate the population biology and autecology of *T. heliophilum* so that conservation efforts on its behalf can be most effective.

Land ownership patterns within the range of *Thalictrum heliophilum* are complex. Despite its narrow range, this species is found on lands administered by the BLM (White River, Grand Junction, and Glenwood Springs Resource Areas), the Department of Energy, the USFS (White River and Grand Mesa national forests), and numerous private landowners, including several oil companies. Two of the occurrences fall partially within the East Douglas Creek and South Cathedral Bluffs Areas of Critical Environmental Concern, which the BLM administers. South Cathedral Bluffs is also a designated Colorado Natural Area. Another occurrence is found within a Colorado Natural Area at Mount Callahan; this area is on private land and is managed in cooperation with Occidental Oil Company.

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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) of the USDA Forest Service (USFS). *Thalictrum heliophilum* is the focus of an assessment because it is a designated sensitive species in Region 2. Within the National Forest System, a sensitive species is a plant or animal whose population viability is identified as a concern by a Regional Forester because of significant current or predicted downward trends in abundance or significant current or predicted downward trends in habitat capability that would reduce its distribution (USDA Forest Service 2002a). A sensitive species requires special management, so knowledge of its biology and ecology is critical.

This assessment addresses the biology of *Thalictrum heliophilum* throughout its range in Region 2. The broad nature of the assessment leads to some constraints on the specificity of information for particular locales. This introduction defines the goal of the assessment, outlines its scope, and describes the process used in its production.

Goal of Assessment

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

Scope of Assessment

The *Thalictrum heliophilum* assessment examines the biology, ecology, conservation, and management of this species with specific reference to the geographic and ecological characteristics of Region 2. Although some of the literature on *Thalictrum* species may originate from field investigations outside the region, this document places that literature in the ecological and social contexts of the central Rocky Mountains. Similarly, this assessment is concerned with reproductive behavior, population dynamics, and other characteristics of *T. heliophilum* in the context of the current environment rather than under historical conditions. The evolutionary environment of the species is considered in conducting the synthesis, but placed in a current context.

In producing the assessment, peer-reviewed literature, non-refereed publications, research reports, and data accumulated by resource management agencies and other investigators were reviewed. Other than the original published description, there are no peer-reviewed publications devoted to *Thalictrum heliophilum*; it is, however, mentioned in a few sources. Because basic research has not been conducted on many facets of the biology of *T. heliophilum*, literature on its congeners was used to make inferences. All known publications on *T. heliophilum* are referenced in this assessment, and many of the experts on this species were consulted during its synthesis. Specimens were viewed at RM (Rocky Mountain Herbarium), COLO (University of Colorado Herbarium), CS (Colorado State University Herbarium), KHD (Kalmbach Herbarium, Denver Botanic Gardens), and GREE (University of Northern Colorado).

The assessment emphasizes peer-reviewed literature because this is the accepted standard in science. Non-refereed publications or reports were regarded with greater skepticism, but they were used in the assessment since there is very little peer-reviewed literature that specifically addresses *Thalictrum heliophilum*. Much of the information about past and current conditions affecting *T. heliophilum* was compiled through conversations with land managers and other agency employees. For an unstudied species such as *T. heliophilum*, these personal communications constitute an important body of knowledge and can provide a baseline for more formal investigations. Unpublished data (e.g., Natural Heritage Program records, specimen labels) provided historical information, including from individuals who could not be contacted during the preparation of this assessment.

Treatment of Uncertainty in the Assessment

Science represents a rigorous, systematic approach to obtaining knowledge. Competing ideas regarding how the world works are measured against observations. However, because our descriptions of the world are incomplete and observations limited, science

focuses on approaches for dealing with uncertainty. A commonly accepted approach to science is based on a progression of critical experiments to develop strong inference (Platt 1964). However, it is difficult to conduct strong experiments that produce clean results in the ecological sciences. Often, observations, inference, good thinking, and models must be relied on to guide our understanding of ecological relations. Confronting uncertainty, then, is not prescriptive. In this assessment, the strength of evidence for particular ideas is noted and alternative explanations described when appropriate.

Treatment of this Document as a Web Publication

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

Peer Review of This Assessment

Assessments developed for the Species Conservation Project were peer reviewed prior to release on the Web. Peer review for this species assessment was administered by the Society for Conservation Biology. Two reviewers provided comments that were synthesized by USFS editors. Peer review is intended to improve the quality of writing and to increase the rigor of the assessment.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Thalictrum heliophilum is listed as a sensitive species in Region 2 (USDA Forest Service 2002a). It is known from only one location on National Forest System land, on the boundary between the Grand Mesa and White River national forests in west-central Colorado. *Thalictrum heliophilum* is considered a sensitive species (USDA Forest Service 2002b) by the USFS because

1) its habitat is limited on National Forest System land, and only one location has been documented
2) its habitat is vulnerable to vegetation management
3) the known occurrence on National Forest System land is small and isolated.

When we began writing this assessment, *Thalictrum heliophilum* was ranked globally vulnerable (G3) by NatureServe (2005) and the Colorado Natural Heritage Program (2005). This study provided us with information to support a rank change to globally imperiled (G2). Because *T. heliophilum* is only found in Colorado, it is also considered imperiled (S2) by the Colorado Natural Heritage Program (2005). For details of NatureServe's ranking system, see the **Definitions** section. *Thalictrum heliophilum* is considered imperiled because it is known from 18 occurrences, only 12 of which contain at least 1,000 plants. The remaining six occurrences report 100 or fewer individuals. The species and its habitat are also imperiled by oil shale mining, oil and gas development, exotic plants, small population size, grazing and trampling by wild ungulates, and climate change.

Seven of the 18 known occurrences of *Thalictrum heliophilum* are on public land managed by the BLM (White River, Grand Junction, and Glenwood Springs Field Offices). One occurrence is known from Department of Energy land. Twelve occurrences are at least partly on private land.

Two occurrences of *Thalictrum heliophilum* fall partially within Areas of Critical Environmental Concern (ACEC) managed by the BLM; occurrence 4 (**Table 1**) is within the South Cathedral Bluffs ACEC, and occurrence 2 (**Table 1**) is within the East Douglas Creek ACEC. ACECs are managed to maintain environmental quality, yet allow multiple uses (USDI Bureau of Land Management 1996). The South Cathedral Bluffs ACEC is closed to oil and gas leasing (USDI Bureau of Land Management 1996), but the East Douglas Creek ACEC is open to this use (Meagley personal communication 2005). A 316-acre portion of South Cathedral Bluffs is also a designated Colorado Natural Area, as is the area that supports occurrence 20 (**Table 1**) on Mount Callahan. The Mount Callahan site supports the largest known occurrence of *T. heliophilum* and is designated a Colorado Natural Area in cooperation with the private land owner, Occidental Oil Company (O'Kane 1988, Colorado State Parks 2005). Although designation of Colorado Natural Areas calls attention to the significance of the sites, it provides no legal protection, and participation is completely voluntary. Natural Area

Table 1. Summary data for the 18 known occurrences of *Thalictrum heliophilum*. Location names are provided as a useful reference, rather than to identify a specific place on the ground. Habitat descriptions are summarized from herbarium labels, field notes, and personal communications (Colorado Natural Heritage Program 2005). While researching element occurrence records of this species, it became apparent that many occurrences should be combined. The current G2S2 conservation rank reflects the new number of occurrences.

CNHP Occurrence Number	County	Location Name	Land Ownership / Management	Date Last Observed	Observers	Approximate plant count	Approximate occupied habitat (acres)	Elevation (ft.)	Site description, habitat information
1	Rio Blanco	Timber Gulch	USDI Bureau of Land Management (BLM) White River Resource Area	Jun-1982	R. Popp and T. Naumann	15	Not known. Assume 6	7,360	Green River Shale, Mahogany Zone. Aspect: North. Slope: 20 degrees. Associated taxa: *Symphoricarpos*, *Quercus gambelii*, *Heuchera*, and *Ribes*
2 (includes former occurrence numbers 3, 5, 6, and 8)	Rio Blanco	Soldier Creek	BLM White River Resource Area	19-Jul-1984	J. Anderson, J. Riefler, W. Baker and T. Naumann	1,455	116	8,200 to 8,800	Parachute Creek Member Green River Shale. Slope: 20 to 70 degrees. Soil: decomposed shale. Aspect: Northwest and East. Associated taxa: *Agropyron*, *Symphoricarpos*, *Pteryxia hendersonii*, *Holodiscus dumosus*, *Clematis*, *Astragalus lutosus*, *Chrysothamnus*, *Astragalus tenellus*, *Machaeranthera. grindelioides.*, *Amelanchier alnifolia*, *Eriogonum lonchophyllum*, and *Oryzopsis*
4 (includes former occurrence numbers 19, 22, and 33)	Rio Blanco	Cathedral Bluffs	BLM White River Resource Area Private: ARCO/ EQUIT, Mobil	08-Jul-1993	W. Kelley, T. Naumann, M. Waters, R. Popp, J. Anderson, S. Allard, J. Walker, K. Wiley-Eberle, W. Jennings, J.A. Erdman, S. O'Kane	20,800	852	8,200 to 8,500	Bare cliff in the Parachute Creek Member of the Green River Formation. Aspect: Southwest Slope: 30 to 90 degrees. Soil: clay, loose gravel and shale. Associated taxa: *Quercus*, *Eriogonum*, *Cirsium*, *Pteryxia hendersonii*, *Lesquerella*, *Galium*, *Astragalus*, *Antennaria*, *Agropyron*, *Astragalus lutosus*, *Eriogonum lonchophyllum*, *Agoseris*, *Cymopterus hendersonii*, *Mentzelia multicaulis*, *Gentiana heterosepala*, *Holodiscus*, *Calylophus*, *Machaeranthera grindelioides*, *Lesquerella parviflora*, and *Leptodactylon pungens*
7	Garfield	Sheep Trail Hollow	Private	20-Jun-1981	P. Nicholas	Not known. Assume 10	Not known. Assume 6	8,500	None provided

Table 1 (cont.).

CNHP Occurrence Number	County	Location Name	Land Ownership / Management	Date Last Observed	Observers	Approximate plant count	Approximate occupied habitat (acres)	Elevation (ft.)	Site description, habitat information
9 (includes former occurrence numbers 18 and 37)	Garfield	Wheeler Gulch	Private: Mobil Oil. Department of Energy, Naval Oil Shale Reserve Private: Union Oil Company of California (UNOCAL)	20-Aug-1996	S. Spackman, R. Rondeau, K. Carsey, and K. Fayette. J. Anderson	2,000	52	7,800 to 8400	Parachute Creek Member Green River Formation. Aspect: South, West-Northwest. Soil: decomposed shale. 45°+ plus slope. Associated taxa: *Amelanchier utahensis*, *Holodiscus dumosus*, *Ericameria nauseosa*, *Symphoricarpos*, *Ribes*, *Eriogonum lonchophyllum*, *Galium coloradense*, *H. dumosus*, *Artemisia tridentata*, *Cirsium barnebyi*, and *Pseudotsuga menziesii* (approx. 20 percent total cover at most)
10 (includes former occurrence number 26)	Garfield	Henderson Ridge	Private BLM: Grand Junction Resource Area	31-Jul-1987	W.A. Kelley and S.D. High, R. Dorn, R.W. Lichvar	1,770	50	8,000 to 8,100	Green River Formation. Aspect: South. Slope: 44-50 percent. Associated taxa: *Holodiscus dumosus*, *Lesquerella parviflora*, *Cirsium*, *Pseudotsuga menziesii*, *Juniperus*, *H. dumosus*, *Galium coloradense*, and *Picea*
11 (includes former occurrence .number 29)	Garfield	Deer Park Gulch	Private: Getty Oil	03-Jun-1983	Camp, Dresser, and McKee, Harner & Assoc., T. Mustard	8,600	86	6,500 to 8,410	Scree slope, barren talus in Green River Formation. Slope: 60 to 80 percent. Aspect: South. Mixed shrubland
12 (includes former occurrence number 13)	Garfield	Granlee Gulch	Private: UNOCAL	09-Aug-1984	Harner & Assoc.	100	12	6,300 to 6,400	Parachute Member Green River Formation. Aspect: West-Northwest. Slope: 12 to 20 percent. Soil: decomposed shale
14 (includes former occurrence numbers 15, 16, 17, and 36)	Garfield	East Fork Parachute Creek	Private: UNOCAL	09-Jul-1996	Harner & Associates, S. Spackman, K. Carsey, and K. Fayette	75	98	6,250 to 7,400	Barren shale talus slopes, Parachute Member Green River Formation. Aspect: Southeast-Southwest, North. Slope: 60 to 80 percent. Occurs with *Mentzelia argillosa*, *Quercus gambelii*, *Amelanchier "alnifolia"*, and *Symphoricarpos*. The vegetation cover was 5 to 20 percent

Table 1 (cont.).

CNHP Occurrence Number	County	Location Name	Land Ownership / Management	Date Last Observed	Observers	Approximate plant count	Approximate occupied habitat (acres)	Elevation (ft.)	Site description, habitat information
20	Garfield	Mount Callahan	Private: Occidental Oil	08-Jul-1996	S. Spackman, R. Rondeau, K. Carsey, C. Scheck, P. Lyon, and K. Fayette. S. O'Kane, J. Anderson	100,000	40	8,000 to 8,480	Parachute Creek Member of the Green River Formation. Generally south facing 30 to 60 percent slopes of white to orange brown shale. Aspect: South-Southeast, South-Southwest. Slope: 5 to 80 percent. Soil: "egg-shell" shale. Associates are *Penstemon debilis*, *Monardella odoratissima*, *Cirsium calcareum*, *Holodiscus dumosus*, *Mentzelia argillosa*, *Chrysothamnus*, *Eriogonum lonchophyllum*, *Physaria*, *Galium coloradense*, *Aletes anisatus*, *Cercocarpus*, *Agropyron*, and *Festuca dasyclada*
21	Garfield	Dry Fork Kimball Creek	USDA Forest Service Grand Mesa National Forest and White River National Forest	24-Jun-1995	B. Johnston, Colorado Natural Areas Program	"many", assume 100	160	8,200 to 8,660	Parachute Creek Member of the Green River Formation, in soil pockets among talus. Also on steep, bare talus. Aspect: South. Associated taxa: *Astragalus lutosus*, *Oryzopsis hymenoides*, and *Lesquerella parviflora*. Slopes criss-crossed by numerous deer and elk trails that help to keep soils mobile and slopes relatively barren
23	Garfield	Horse Mountain	BLM Grand Junction Resource Area	08-Jul-1987	R.W. Lichvar	7,000	160	8,200	Green River Formation. Aspect: Southwest Slope: 33 percent. Associated taxa: *Agropyron*, *Oryzopsis*, *Linum*, and *Eriogonum lonchophyllum*
25 (includes former occurrence numbers 31 and 38)	Garfield	Brush Mountain	BLM Grand Junction Resource Area	29-Jun-2000	R. Dorn, R.W. Lichvar, P. Lyon	6,125	126	8,000 to 8,600	Steep, barren slopes of Green River shale. Aspect: South, Southwest. Slope: 45 to 70 percent. Associated taxa: *Amelanchier alnifolia*, *Ribes cereum*, *Juniperus*, *Oryzopsis*, *Cirsium calcareum*, *Penstemon cespitosus*, *Galium coloradense*, *Holodiscus dumosus*, *Mahonia repens*, *Symphoricarpos oreophilus*, *Prunus virginiana*, *Quercus gambelii*, some *Lesquerella parviflora* and *Argillochloa dasyclada*, scattered *Pseudotsuga menziesii*. Surrounding mesa top has sagebrush/snowberry community

Table 1 (concluded).

CNHP Occurrence Number	County	Location Name	Land Ownership / Management	Date Last Observed	Observers	Approximate plant count	Approximate occupied habitat (acres)	Elevation (ft.)	Site description, habitat information
27	Garfield	4A Ridge	BLM Grand Junction Resource Area	13-Jul-1987	R.W. Lichvar	4,675	160	8,000	Green River Formation. Aspect: South. Slope: 33 percent. Associated taxa: *Amelanchier*, *Holodiscus*, *Symphoricarpos*, and *Festuca*
28	Garfield	Tom Creek Canyon	Private: Getty Oil/Texaco Oil	10-Jun-1993	Harner & Assoc., R. Rondeau	2,000	6	6,800	Green River Formation. Aspect: all. Soil: scree slope. Slope: various
30	Garfield	Conn & Cascade Canyons	Private: Occidental Oil	10-Jun-1993	R. Rondeau, Harner & Assoc.	1,000	6	6,200 to 8,000	Open, loose scree slope habitats. Green River Formation. Aspect: all. Soil: scree. Slope: 40 percent. The slopes are steep, with shale landslides common. Associated taxa: *Mentzelia* spp., unknown umbel and *Euphorbia* spp. *Lesquerella* growing in steep shale landslides - very open sparsely vegetated but the dominant is *Thalictrum*.
34	Garfield	Bear Cabin Gulch	Private: Exxon	24-Jun-1993	R. Rondeau and S. Spackman	1,000	12	6,200 to 7,500	Loose shale scree slopes. Slope: 35+ percent. Aspect: Southwest, Southeast. With *Oryzopsis hymenoides* and *Mentzelia argillosa*
35	Garfield	West Fork Parachute Creek	Private: UNOCAL	22-June-1993	G. Kittel and D. Randolph	10	6	6,840 to 7,200	Loose shale scree slopes. Slope: 35+ percent. Growing out by itself but other plants in vicinity are *Prunus virginiana*, *Toxicodendron rydbergii*, *Holodiscus dumosus*, *Amelanchier utahensis*, *Galium* spp., *Cirsium* spp., and *Symphoricarpos oreophilus*
TOTAL						**156,735**	**1,954**		

status can change at any time if the landowner manager is not interested in maintaining the designation.

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

USFS policy requires that activities be managed to avoid disturbances that would result in a trend toward federal listing or loss of population viability of designated sensitive species like *Thalictrum heliophilum* (see Forest Service Manual 2670). The current forest management plan in use by the White River National Forest specifies that each known occurrence of *T. heliophilum* on the forest be monitored every five years, and that surveys be conducted for this species prior to any potentially harmful activities being allowed in potential habitat (USDA Forest Service 2002b).

Thalictrum heliophilum is not on the Colorado BLM State Director's sensitive species list. Inclusion on this list (USDI Bureau of Land Management 2000) would call attention to the species as a potential management concern, but would not mandate specific protection measures. BLM managers are responsible for collecting and maintaining information on sensitive species "to determine if designation as a candidate or listed species is warranted or if special management considerations are needed" (USDI Bureau of Land Management 2000).

Thalictrum heliophilum is not listed as threatened or endangered under the federal Endangered Species Act. The U.S. Fish and Wildlife Service did list it as a Category 2 species (O'Kane 1987, O'Kane 1988, Spackman et al. 1997a), but this category is no longer used. Category 2 species may have been threatened or endangered, but sufficient information available to substantiate listing under the Endangered Species Act was not available (Spackman et al. 1997a).

Thalictrum heliophilum has not been found on lands managed by the state of Colorado, and it does not have any state-level status. There are no laws in place that protect *T. heliophilum* on private lands, where most plants reside. Current laws and regulations are therefore clearly inadequate to conserve the species within its native range.

No management plans have been drafted that specifically address the conservation needs of *Thalictrum heliophilum*. This species has no legal protection that would prevent the destruction of habitat or individuals. As of this writing, a conservation strategy has not been written for this species at a national or regional level by the USFS or any other federal agency. Changes in federal land use plans are needed to ensure the long-term viability of populations of *T. heliophilum*.

Thalictrum heliophilum occurs in nine Potential Conservation Areas (PCAs) identified by the Colorado Natural Heritage Program (2005): Mount Callahan, Parachute Creek, Parachute Creek Watershed, South Cathedral Bluffs, 4A Ridge, Horse Mountain, Clear Creek, Conn Creek, and Dry Fork Kimball Creek. These PCAs include most of the known occurrences of *T. heliophilum*. The Colorado Natural Heritage Program has supplied information about these areas to the USFS (Colorado Natural Heritage Program 2004) and Garfield County (Lyon et al. 2001) to facilitate awareness of this species and its habitat during planning and management activities. PCAs have not been delineated for some locations of *T. heliophilum*, especially in Rio Blanco County. A PCA is an estimate of the primary area supporting the long-term survival of targeted species and plant communities, based on an assessment of the biotic and abiotic factors affecting the persistence and population viability of the targets within the area (Colorado Natural Heritage Program 2005).

Biology and Ecology

Classification and description

Thalictrum heliophilum Wilken & DeMott (Cathedral Bluff meadow-rue or sun-loving meadowrue) is a member of the Ranunculaceae, also known as the buttercup or crowfoot family (USDA Natural Resources Conservation Service 2005). The Ranunculaceae includes approximately 1,900 to 2,500 species in 46 to 60 genera (Zomlefer 1994, Whittemore and Parfitt 1997). The Ranunculaceae is in class Magnoliopsida (dicotyledons), subclass Magnoliidae, and order Ranunculales (USDA Natural Resources Conservation Service 2005). The Ranunculaceae is found primarily in temperate to boreal regions of the Northern Hemisphere and is especially diverse in eastern North America and eastern Asia (Zomlefer 1994).

Linnaeus first described the genus *Thalictrum* in 1753 (Weber and Wittmann 2001). Some of the most notable characteristics that distinguish *Thalictrum* from other genera in the Ranunculaceae include its radially symmetrical unisexual or bisexual flowers, a lack of petals and involucral bracts, and compound leaves (Whittemore and Parfitt 1997). Species of *Thalictrum* are found throughout the world, but the primary distribution is within temperate regions. The genus

Thalictrum includes approximately 120 to 200 species (Park and Festerling 1997), and five species, including *T. heliophilum*, are known from the western slope of Colorado (Weber and Wittmann 2001).

In 1992, the Catalog of the Colorado Flora by Weber and Wittmann (1992) placed *Thalictrum* in the Coptaceae (Gregory) Love & Love. In 1996 and 2001 the Colorado Flora by Weber and Wittmann (1996 and 2001) placed *Thalictrum* in the Thalictraceae Rafinesque based on plants being (mostly) dioecious, the absence of petals, and compound leaves (Weber and Wittmann 2001). These families are closely related to the Ranunculaceae, and some authors consider them to be part of this larger group (Watson and Dallwitz 1992 onwards). In its more inclusive sense, the Ranunculaceae is described in the Flora of North America, Volume 3 (Whittemore and Parfitt 1997). Whittemore and Parfitt do not mention the Thalictraceae.

Regardless of the family placement, there has been little controversy regarding the distinctiveness of plants described as *Thalictrum heliophilum* since it was first described in 1983 (Wilken and DeMott 1983, Weber and Wittmann 1992, Kartesz 1999, Weber and Wittmann 2001, NatureServe 2004, USDA Natural Resources Conservation Service 2004). However, the taxonomy of this genus has not been rigorous (Weber personal communication 2006). It is possible that *T. heliophilum* is synonymous with *T. foetidum* Linnaeus, a species widespread in southern Eurasia. There are a number of species and genera in Colorado that are also known from Eurasia (Weber personal communication 2006). If *T. heliophilum* is found to be synonymous with *T. foetidum*, then this would be another example of a species with relictual populations in Colorado from a once more widely distributed Oroboreal flora (Weber 2003).

The genus *Thalictrum* has been divided into six sections (Park and Festerling 1997). *Thalictrum heliophilum* is in section *Heterogamia*, which includes 25 species from Mexico and North America (Park and Festerling 1997). The closest relatives to *T. heliophilum* are apparently other members of the section *Heterogamia*. Members of section *Heterogamia* that are also found on the western slope of Colorado include *T. venulosum*, *T. occidentale*, and *T. fendleri* (Park and Festerling 1997). *Thalictrum venulosum* and *T. occidentale* are not included in the Flora of Colorado (Weber and Wittmann 2001). *Thalictrum occidentale* may not be distinct from *T. venulosum* (Park and Festerling 1997), and Weber and Wittmann (1992) reported that the distinction between *T. fendleri* and *T. venulosum* is not convincing. Weber (2003) stated that *T. heliophilum* belongs to the section *Euthalictrum*. This section is not reported in the Flora of North America (Park and Festerling 1997).

History of knowledge

Thalictrum heliophilum was first collected in 1977 by James A. Erdman at Cathedral Bluffs in western Rio Blanco County, Colorado, but it was not recognized as belonging to a new species at that time. The specimen was originally identified as *T. fendleri* and not annotated to reflect the correct identification, *T. heliophilum*, until 1982, by Dr. William Weber at the University of Colorado Museum Herbarium. In 1980, Karen Wiley, then a botanist with the BLM, collected *T. heliophilum* once again on the Cathedral Bluffs, noticing that its morphology and habitat appeared to be different from that of *T. fendleri*, the species to which at least two botanical keys pointed, Harrington (1954) and Boivin (1944). Following this lead, Dieter Wilken returned to the area in 1982, collected a specimen near the confluence of Lake Creek and Cathedral Creek, and used this specimen to describe *T. heliophilum* in a 1983 issue of Brittonia (Wilken and DeMott 1983), choosing a specific epithet that reflected its open, sunny habitat. While reviewing specimens for publication of this new taxon, Wilken and DeMott discovered three other collections of *T. heliophilum* from Rio Blanco and Garfield counties that are noted in the original description (Wilken and DeMott 1983). One of these collections was made in 1981 by Nicholas at the east end of the Roan Plateau in Garfield County, one was made in 1981 by Allard and Walker near the first known location at Cathedral Bluffs, and another was made in 1982 by Baker and Naumann near Soldier Creek in Rio Blanco County (Wilken and DeMott 1983).

From the time of its discovery through the 1980s, there was a great deal of botanical research the Piceance Basin of Colorado (e.g., Peterson and Baker 1982, Harner and Associates 1984), and *Thalictrum heliophilum* was documented in several other locations. Popp and Naumann collected a specimen at Timber Gulch in Rio Blanco County (occurrence 1 in **Table 1**), bringing the total known occurrences for Rio Blanco County to three; no new occurrences in this county have been documented since 1982. Several new locations were identified in Garfield County by J. Anderson, S. O'Kane, R. Dorn, R. Lichvar, T.S. Mustard, T. Naumann, W. Kelley, S. High, and others. In 1986, Barry Johnston of the USFS documented what is still the only location south of the Colorado River, and the only record for Mesa County (Colorado Natural

Heritage Program 2005). This is also the only location known on National Forest System land.

In a status report on *Thalictrum heliophilum* written for the U.S. Fish and Wildlife Service, O'Kane (1987) recommended that it be listed as a federally threatened species. He based his recommendation on the species' rarity and the threats to the persistence of plants, particularly oil shale mining (O'Kane 1987). At this time, *T. heliophilum* was reported to be distributed in 21 occurrences (O'Kane 1987). Since that time, the Colorado Natural Heritage Program (CNHP) has lumped some of these occurrences because of their close proximity and the apparent connectedness of habitat. Today, CNHP considers the 21 occurrences in O'Kane's status report to represent a total of 11 occurrences. O'Kane evidently did not have reports from Harner and Associates for 1983 surveys conducted in Conn and Cascade Canyons that document two additional occurrences. In 1987, following publication of O'Kane's status report, three more occurrences were located in Garfield County; 16 occurrences were known by the end of 1987 (Colorado Natural Heritage Program 2005).

At this time, *Thalictrum heliophilum* was maintained as a Category 2 candidate for listing as Threatened or Endangered (O'Kane 1987) by the USFWS. In 1988, Steve O'Kane published Colorado's Rare Flora (O'Kane 1988) and suggested that the inventory work for *T. heliophilum* was complete and the level of imperilment depended on the likelihood of extensive oil shale development in the area.

In 1993, two more occurrences of *Thalictrum heliophilum* were located by Kittel, Rondeau, Randolf, and Spackman, bringing the total known to 18 occurrences in three counties (Colorado Natural Heritage Program 2005). No more occurrences have been located since 1993, but eight have been revisited and updated.

From 1993 to 2004, numerous botanists who were aware of the significance of occurrences of *Thalictrum heliophilum* conducted research within the known range of *T. heliophilum* and surrounding areas (Rondeau et al. 1997, Spackman et al. 1997b, Lyon et al. 2001, Scheck personal communication 2005, Lyon personal communication 2005, Colorado Natural Heritage Program 2005). No new occurrences were found, but some boundaries were expanded by Rondeau, Lyon, and Spackman.

Non-technical description

Thalictrum heliophilum plants are perennial, dioecious, and stand 1.4 to 5 dm tall, typically with a single stem or growing in a cluster of stems connected by two or three short rhizomes. Male and female flowers are radially symmetrical, and are arranged in a many-flowered panicle on the upper half of the stems. Petals are absent. Staminate (male) flowers have four ovate sepals that are about 3 mm long, and stamens about 4 to 6 mm long. Pistillate (female) flowers have four lanceolate to ovate sepals that are about 2 mm long, and four to six pistils. The female flowers produce achenes that are 4 to 5 mm long, laterally compressed, and have three prominent lateral nerves that converge near the achene apex. Sepals are not persistent in fruit. Cauline and basal leaves of *T. heliophilum* are compound, leathery, and tridentate. Cauline leaves are gradually reduced upwards. Roots are fibrous (Wilken and DeMott 1983, O'Kane 1987, Park and Festerling 1997, Spackman et al. 1997a, Lyon et al. 2001). Although the leaves are described as glabrous and glaucous (Wilken and Demott 1983, Park and Festerling 1997, Spackman et al. 1997a), Dr. Weber (personal communication 2006) noted glandular hairs on specimens of *T. heliophilum*.

Thalictrum heliophilum is most similar in appearance to *T. fendleri* (Wilken and DeMott 1983), which occurs within the range of *T. heliophilum* but is generally restricted to shaded sites, usually within stands of *Populus tremuloides* (quaking aspen) and *Symphoricarpos oreophilus* (mountain snowberry). The most reliable characteristic for distinguishing these species is that *T. heliophilum* is shorter, with leathery, glaucous leaflets, and has fewer achenes (Wilken and DeMott 1983, Park and Festerling 1997). The pistillate flowers of *T. fendleri* have seven to 14 carpels while those of *T. heliophilum* have four to six (Wilken and DeMott 1983). Wilken and DeMott (1983) also report that the ultimate leaflets of *T. fendleri* are larger (7 to 20 mm long and 6 to 18 mm wide) than those of *T. heliophilum* (5 to 8 mm long and 4 to 9 mm wide).

Aquilegia barnebeyi (oil shale columbine) occupies similar habitats as *Thalictrum heliophilum*, and the species have been documented growing together. Because the leaves look so much alike, *T. heliophilum* is difficult to distinguish from *A. barnebeyi* when not in flower (Peterson and Baker 1982). However, the leaf venation is different in these species (Weber personal communication 2006). Inventories are best conducted when the plants are in flower or fruit (Peterson and Baker 1982), or searchers must otherwise be able to differentiate between these species.

Published descriptions and other sources

The best single source for a description, range map, illustration, and photographs of *Thalictrum heliophilum* is the Colorado Rare Plant Field Guide (Spackman et al. 1997a; **Figure 1**, **Figure 2**). An illustration and a range map are included in Rare Plants of Colorado (Colorado Native Plant Society 1997), and photographs of the plant and its habitat appear in the 1987 *T. heliophilum* status report (O'Kane 1987). Wilken and DeMott's original description (1983) includes an illustration. The Flora of North America Volume 3 (Park and Festerling 1997) provides an illustration and distribution map. The Center for Plant Conservation website contains photos of the plant and its habitat (Center for Plant Conservation 2005). Weber and Wittmann (2001) is the most readily available and up-to-date source with keys for field identification, but it does not include a full description.

Figure 1. Close up photograph of *Thalictrum heliophilum*, by Susan Spackman Panjabi.

Figure 2. Habitat of *Thalictrum heliophilum*. Photograph by Susan Spackman Panjabi.

The type specimen is housed at the Rocky Mountain Herbarium, with isotypes at the University of Colorado, Colorado State University, New York Botanical Garden, and Brigham Young University (O'Kane 1987). A digital image of Wilken's isotype specimen is available online from the New York Botanical Garden's website (New York Botanical Garden 2005).

Distribution and abundance

Thalictrum heliophilum is a narrowly endemic species known from 18 occurrences in an approximately 32 by 40 mile (52 by 64 km) range in Garfield, Rio Blanco, and Mesa counties, Colorado (**Figure 3**, **Figure 4**). Fourteen of the 18 known occurrences of *T. heliophilum* are found within Garfield County, three are in Rio Blanco County, and one is in Mesa County. These occurrences are estimated to contain 156,735 individuals in less than 2,000 acres of occupied habitat (Colorado Natural Heritage Program 2005). Extensive inventories have been conducted for this and other oil shale endemic plant species, but there is some additional potential habitat that remains to be searched (Johnston personal communication 2005, Lyon personal communication 2005, Rondeau personal

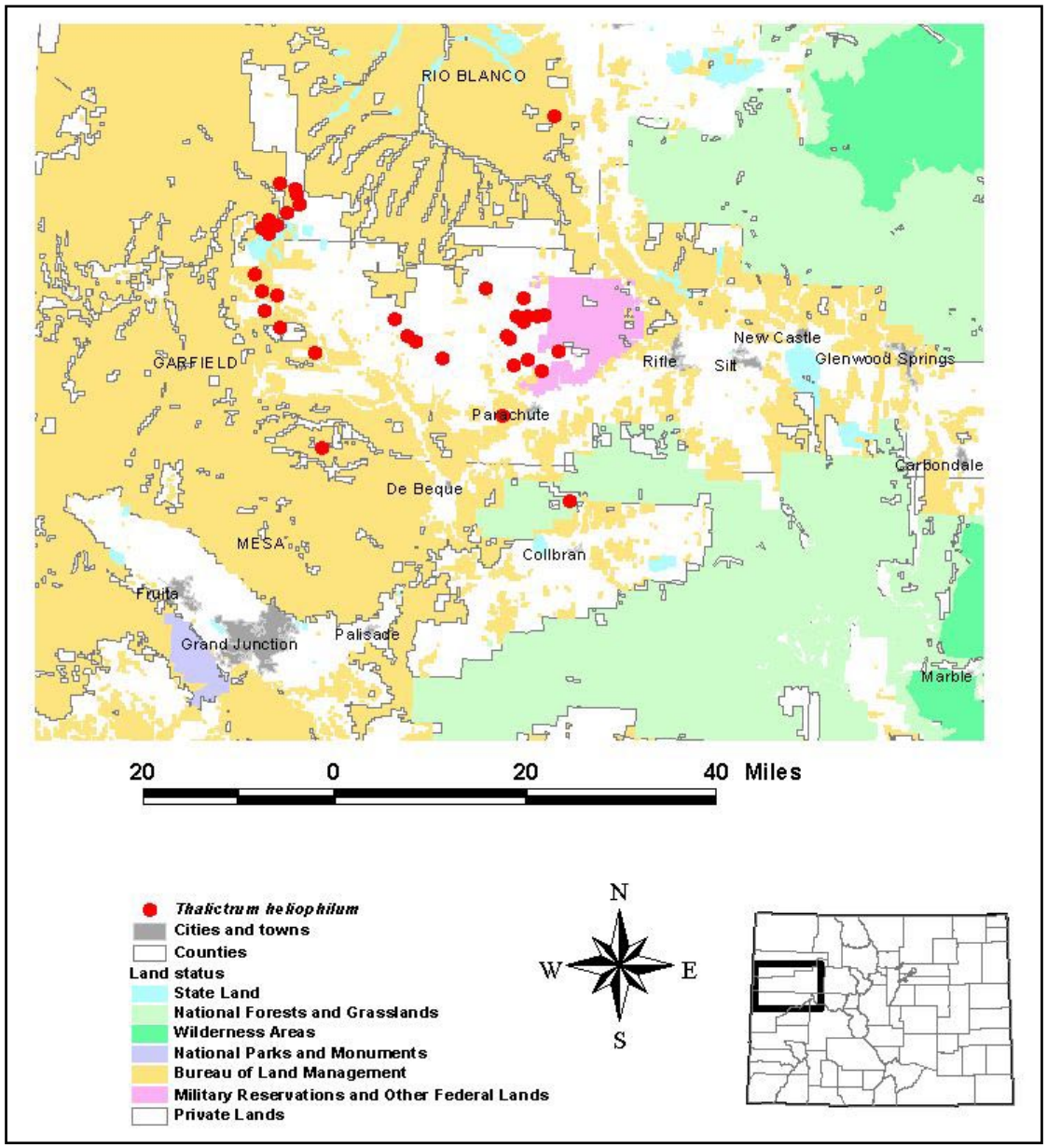

Figure 3. Distribution of *Thalictrum heliophilum* in northwestern Colorado, shown in relationship to land ownership.

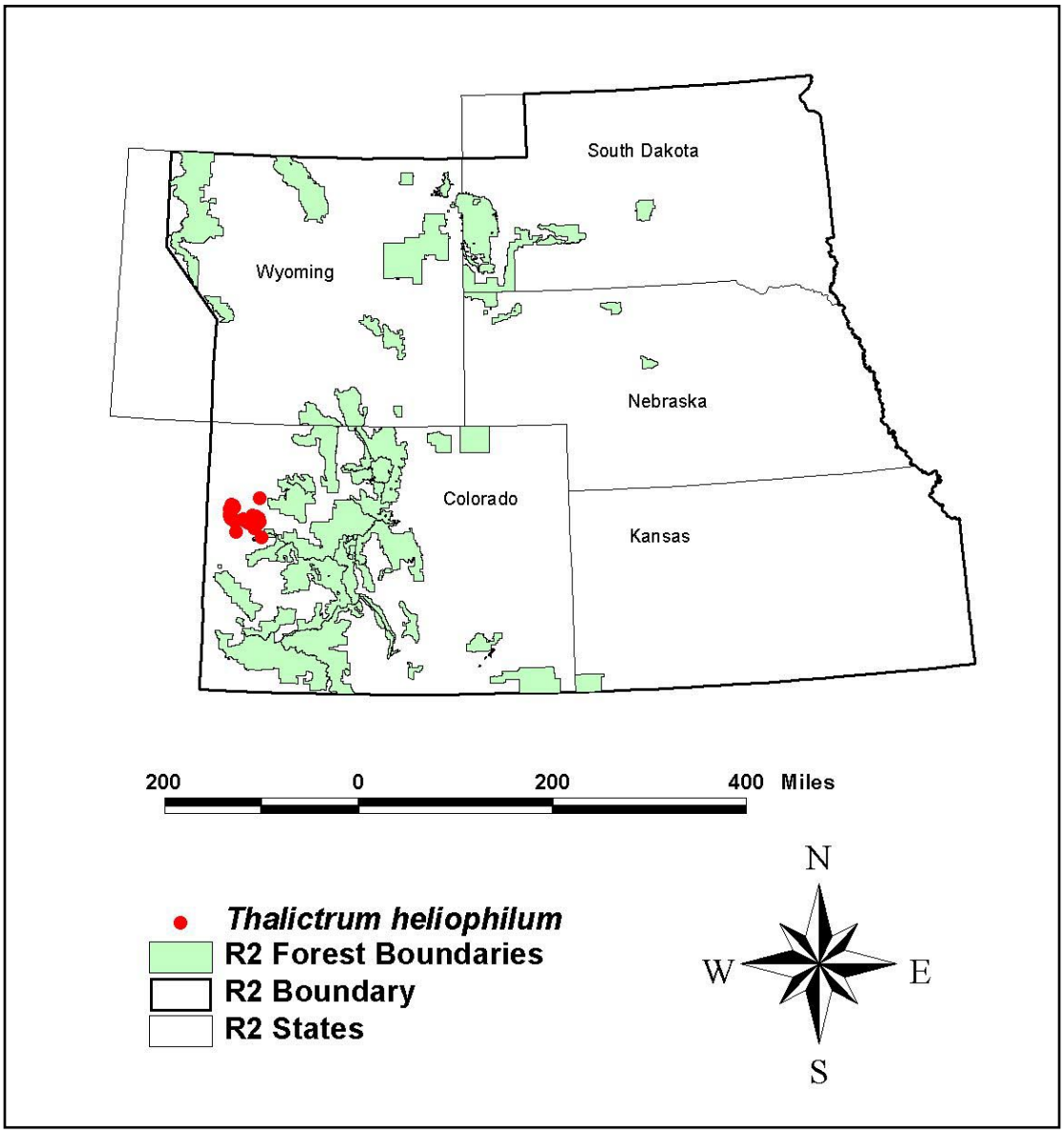

Figure 4. Distribution of *Thalictrum heliophilum* in USDA Forest Service Region 2.

communication 2005, Scheck personal communication 2005). In 2000, Peggy Lyon searched areas in Garfield County that appeared to have potential habitat, but no new occurrences were documented (Lyon personal communication 2005). Many of the occurrence size estimates are based on observations of only a portion of the occurrences (Colorado Natural Heritage Program 2005). For this reason, while it is possible that some of the occurrences are over-estimated, it is also possible that some of the occurrences are much larger than the reported numbers.

Thalictrum heliophilum is found on lands managed by the USFS, the BLM, and the Department of Energy, as well as on private land (**Figure 3**, **Table 1**). The species is known from only one occurrence on National Forest System land, and that occurrence falls along the boundary separating the White River and Grand Mesa national forests. No other occurrences are near National Forest System land (**Figure 3**, **Figure 4**). Additional potential habitat for *T. heliophilum* on National Forest System lands is reported to be very limited (USDA Forest Service 2002b). However, Johnston (personal communication 2005) suggested that unsurveyed potential habitat exists on the Grand Mesa National Forest.

Botanical surveys conducted over the past decade specifically targeted *Thalictrum heliophilum* (e.g., Rondeau et al. 1997, Spackman et al. 1997b, Lyon et

al. 2001, Scheck personal communication 2005). While these surveys failed to locate additional occurrences, the boundaries of several known occurrences were expanded. Limited access to remote areas and private land has made it difficult to search areas within the range of *T. heliophilum* thoroughly. National Forest System land with potential habitat is also poorly surveyed (Johnston personal communication 2005). It is likely that the species is limited to the range as currently defined, but further inventories are necessary to verify this.

There has been no rigorous quantification of *Thalictrum heliophilum* abundance. It is known from 18 occurrences, but the majority of plants are found in just one occurrence; 100,000 of the 156,735 estimated individuals in the entire population are found on Mount Callahan (occurrence 20 in **Table 1**). Twelve of the 18 occurrences report 1,000 or more individuals while the remaining six report 100 or fewer. Only one occurrence, 7, does not have any information regarding size (**Table 1**). Most occurrences (about 55 percent) are estimated to have between 100 to 1000 plants (Colorado Natural Heritage Program 2005). The approximate total known from National Forest System land is about 100 individuals (based on observers reporting that there were "many" plants (Colorado Natural Heritage Program 2005, Johnston personal communication 2005).

Similarly, there has been no rigorous quantification of the total area occupied by *Thalictrum heliophilum*. While some botanists have reported visual estimates of the total acreage of certain occurrences, others have drawn polygons on maps that represent larger areas (Colorado Natural Heritage Program 2005). With this information, we estimate that the total area occupied by the species is less than 2,000 acres (roughly 3 square miles; **Table 1**). Based on conversation with people doing field surveys and observing additional potential habitat, it is likely that the actual occupied habitat is a somewhat larger area (Scheck personal communication 2004, Johnston personal communication 2005, Lyon personal communication 2005, Rondeau personal communication 2005).

The Rare Plants of Colorado (Colorado Native Plant Society 1997) reported that *Thalictrum heliophilum* is also known from Utah, but we found no further information to support this. The occurrence on National Forest System land at Dry Fork Kimball Creek (occurrence 21 in **Table 1**) is the only occurrence known south of the Colorado River, and the only occurrence in the Southern Rocky Mountain Ecoregion. All of the other occurrences are in the Utah High Plateaus Ecoregion (Bailey 1995).

Population trend

More information is needed to infer the population trend of *Thalictrum heliophilum*. Population size estimates presented in **Table 1** are rough. Human impacts to individuals and habitat for *T. heliophilum*, primarily from mining activities and associated infrastructures, suggest that there may have been a downward trend (Colorado Natural Heritage Program 2005).

Population sizes may fluctuate naturally due to annual climatic variation. As *Thalictrum heliophilum* is probably a stress-tolerant species, it is likely that while drought likely reduces or eliminates recruitment of seedlings, juvenile plants may be capable of surviving one or more bad years. Seedlings are sometimes abundant in favorable years (USDA Forest Service 2002b). Population fluctuations may make it difficult to assess long-term population trends.

Habitat

Thalictrum heliophilum is found on open slopes of eroding shale of the Parachute Creek Member of the Green River Formation, between 6,200 and 8,800 ft. (1,890 and 2,682 m) elevation (Wilken and DeMott 1983, Colorado Natural Heritage Program 2005). The Green River Formation is extensive across northwestern Colorado, southwestern Wyoming, and northeastern Utah (Colorado Native Plant Society 1997). *Thalictrum heliophilum* is only found on a subset of this formation, called the Parachute Creek Member. This may be because the Parachute Creek Member includes layers that resist erosion and force groundwater to the surface, creating relatively high levels of soil moisture in an otherwise dry environment (Wilken and DeMott 1983). The sites where *T. heliophilum* are found are nonetheless quite xeric, with no associated mesophytic plant species. This is one of the factors that make *T. heliophilum* stand out from other species of *Thalictrum*; as its scientific name implies, it is the only species of *Thalictrum* in Colorado that grows in full sun (Lyon et al. 2001).

The vascular plant species most commonly associated with *Thalictrum heliophilum* are *Mentzelia rhizomata* (Roan Cliffs blazingstar), *Oryzopsis hymenoides* (Indian ricegrass), *Lesquerella parviflora* (Piceance bladderpod), *Galium coloradense* (Colorado bedstraw), *Eriogonum lonchophyllum* (spearleaf

buckwheat), *Cirsium calcareum* (Cainville thistle), *Cymopterus hendersonii* (Henderson's wavewing), *Holodiscus dumosus* (rock spiraea), *Astragalus lutosus* (dragon milkvetch), and *Chrysothamnus nauseosus* (rubber rabbitbrush) (O'Kane 1987, Colorado Natural Heritage Program 2005). Other frequently associated species include *Calylophus lavandulifolius* (lavenderleaf sundrops), *Cirsium barnebyi* (Barneby's thistle), *Leptodactylon pungens* (granite prickly phlox), *Symphoricarpos oreophilus* (mountain snowberry), *Agropyron spicatum* (bluebunch wheatgrass), *Machaeranthera grindelioides* (rayless tansyaster), and *Amelanchier utahensis* (Utah serviceberry) (O'Kane 1987). **Table 2** is a complete list of vascular plants documented with *T. heliophilum*.

The soils supporting *Thalictrum heliophilum* occurrences are derived from Green River Shale. They are poorly developed and consist of a clay matrix holding together shale chips and channers (O'Kane 1987, Colorado Natural Heritage Program 2005). Precipitation does not penetrate deeply into the soil because of steep slopes and protective cover of shale fragments, and because water binds to the clay particles (O'Kane 1987).

Thalictrum heliophilum has been documented on all aspects, but it is primarily found on south-facing slopes (Colorado Natural Heritage Program 2005). While it is found on nearly flat to very steeply sloping terrain, this species is most often found on 30 to 60 percent slopes (Colorado Natural Heritage Program 2005). All available information regarding habitat for each occurrence is presented in **Table 1**.

To obtain information on the local climate at the *Thalictrum heliophilum* sites, we referred to data collected between 1910 and 2004 and compiled by the Western Regional Climate Center (2005). The closest weather stations within the range of *T. heliophilum* are at Little Hills in Rio Blanco County, Rifle in Garfield County, and Collbran in Mesa County, Colorado. The Little Hills and Collbran weather stations are located at about 6,000 ft., and the Rifle station is at about 5,300 ft. No data were available for a comparable site for the upper end of the elevation range of *T. heliophilum* (8,800 ft.). At these weather stations, the average total annual precipitation is 11 to 15 inches, including an average total snowfall of 38 to 65 inches. The average snow depth is 1 to 2 inches. At all stations, the average maximum temperatures (79 to 90 °F) and average minimum temperatures (38 to 51 °F) are at their highest in June, July, and August (Western Regional Climate Center 2005). Precipitation is distributed evenly throughout the year, as snow in cold months and thunderstorms in the warmer months (O'Kane 1987, Western Regional Climate Center 2005).

Thalictrum heliophilum occurs almost entirely in the Utah High Plateaus Ecoregion. One occurrence on National Forest System Land is in the Southern Rocky Mountain Ecoregion as defined by Bailey (1995). Several occurrences are very near the border of these two ecoregions.

The definitions of high quality and marginal habitat are not clearly understood for *Thalictrum heliophilum*. Areas with natural vegetation with minimal impact from human activities that support dense populations probably represent the best examples of high quality habitat. From this standpoint, the best sites are found at Mount Callahan, Brush Mountain, Wheeler Gulch, Tom Creek Canyon, Bear Cabin Gulch (all in Garfield County), and Cathedral Bluffs in Rio Blanco County (Colorado Natural Heritage Program 2005).

Many areas that support *Thalictrum heliophilum* also support occurrences of other rare plant species. The Piceance Basin and surrounding deposits of Green River Shale is considered a "hot spot" for globally rare and imperiled plant species (Colorado Natural Heritage Program 2005). The rare and imperiled plants species that are found with *T. heliophilum* appear in bold type in **Table 2**.

Reproductive biology and autecology

Very little is known about the reproductive biology and autecology of *Thalictrum heliophilum*. Some authors have speculated that it is a wind-pollinated, obligate out-crossing species (O'Kane 1987), but there have been no studies of its reproductive strategies. *Thalictrum heliophilum* plants are dioecious, and female flowers develop one-seeded fruits, known as achenes. It is not known how long plants of this perennial species live. As a rhizomatous species, *T. heliophilum* may also spread by distributing rhizomes. The relative importance of sexual and vegetative reproduction is not known.

Natural disturbance plays a role in the autecology of *Thalictrum heliophilum*. Although *T. heliophilum* is not always found in disturbed sites, it is commonly found in eroding shale habitats with considerable bare ground, and it has been found along roads and in areas that are traveled by Rocky Mountain bighorn sheep

Table 2. List of taxa that have been documented with *Thalictrum heliophilum*. All species are native to Colorado. Species listed in bold are considered rare or imperiled in Colorado (Colorado Natural Heritage Program 2005).

Agoseris spp.	*Heuchera* spp.
Agropyron spicatum = Pseudoroegneria spicata	*Holodiscus dumosus*
Aletes anisatus	*Juniperus* spp.
Amelanchier alnifolia	*Leptodactylon pungens*
Amelanchier utahensis	***Lesquerella parviflora***
Antennaria spp.	*Lesquerella* spp.
Argillochloa dasyclada = Festuca dasyclada	*Linum* spp.
Artemisia tridentata	*Machaeranthera grindelioides*
Astragalus chamaeleuce	*Mahonia repens*
Astragalus lutosus	***Mentzelia argillosa = Mentzelia rhizomata***
Astragalus spp.	*Mentzelia multicaulis*
Astragalus tenellus	*Mentzelia* spp.
Calylophus lavandulifolius	*Monardella odoratissima*
Cercocarpus spp.	*Oryzopsis hymenoides = Achnatherum hymenoides*
Chrysothamnus nauseosus = Ericameria nauseosa	*Penstemon caespitosus*
Cirsium barnebyi	***Penstemon debilis***
Cirsium calcareum	*Physaria* spp.
Cirsium spp.	*Picea* spp.
Clematis spp.	*Prunus virginiana*
Eriogonum lonchophyllum	*Pseudotsuga menziesii*
Eriogonum spp.	*Pteryxia hendersonii = Cymopterus hendersonii*
Euphorbia spp.	*Quercus gambelii*
Festuca spp.	*Ribes cereum*
Galium coloradense	*Ribes* spp.
Galium spp.	*Symphoricarpos rotundifolius* (*oreophilus*)
Gentiana heterosepala	*Toxicodendron rydbergii*
Gentianella tortuosa	

(*Ovis canadensis canadensis*), mule deer (*Odocoileus hemionus*), and elk (*Cervus elaphus*) (Colorado Natural Heritage Program 2005).

Pollinators and pollination ecology

Plants in the genus *Thalictrum* are known to be wind-pollinated (Watson and Dallwitz 1992 onwards, Zomlefer 1994), but they may also be pollinated by insects (Davis 1997). The lack of flower petals in *T. heliophilum* is a strong indicator of reliance on wind pollination. Floral nectaries that would attract insect pollinators are absent in the genus *Thalictrum* (Watson and Dallwitz 1992 onwards). *Thalictrum pubescens* was found to be at least partially wind-pollinated. Plants enclosed in cheesecloth, which excluded insects but not wind, were still able to set seed (Davis 1997). Primary insect visitors to *T. pubescens* are Syrphid flies (Davis 1997). Similar research has not been conducted for *T. heliophilum*.

O'Kane (1987) reported that because *Thalictrum heliophilum* plants are dioecious, they must outcross, and that plants are probably wind-pollinated. Having female flowers on separate plants could be a disadvantage if insects are the primary pollination agent, because some insects will not visit female plants that do not have a pollen reward (Charlesworth 1993). Unisexuality (including a dioecious habit) is often correlated with wind pollination or pollen transfer by small pollinator species (Charlesworth 1993).

Phenology

Thalictrum heliophilum flowers in June and July, and fruit development proceeds through August

(O'Kane 1987, Spackman et al. 1997a). Vegetative growth may begin in May (O'Kane 1987), or even earlier because of the high degree of exposure and lack of snow cover at many sites (Coles personal communication 2006). Because *T. heliophilum* occurs on xeric sites, recruitment events may coincide with wet or otherwise favorable years during which seedlings can become established.

Fertility and propagule viability

Very little is known about the fertility and propagule viability of *Thalictrum heliophilum*. Studies of *T. cooleyi*, a federally listed endangered species of wet habitats in the southeastern United States, found that seed production was positively correlated with plant height and adequate rainfall (U.S Fish and Wildlife Service 1994). O'Kane (1988) reported that oil companies have used *T. heliophilum* for revegetation projects with great success. However, the details of how the plants were introduced to the reclamation sites are not known. O'Kane (1987) speculated that the seedling roots of *T. heliophilum* probably follow cracks in the shale where there is more moisture (O'Kane 1987).

Seed longevity and germination requirements for *Thalictrum heliophilum* are not known. Other species of *Thalictrum* are easily propagated from seed (O'Kane 1987). For some *Thalictrum* species, the seeds require no treatment. For others, up to three months of cool, moist storage (stratification) at 31 to 41 °F is required for germination (O'Kane 1987). These conditions are meant to mimic the natural conditions in which germination occurs for each species. About 30 to 40 species of *Thalictrum* worldwide have been grown for horticultural uses (O'Kane 1987). Seeds of *T. cooleyi* that were collected and stored for more than one year failed to germinate, so seed longevity is thought to be short for this species. Seeds that did germinate (20 percent success) were fresh seeds that were cold-stratified for several weeks (U.S. Fish and Wildlife Service 1994).

The Denver Botanic Garden has performed germination and growth tests on *Thalictrum heliophilum* (Center for Plant Conservation 2005), but results were not available for this publication (Grant personal communication 2005).

Dispersal mechanisms

Little is known about how *Thalictrum heliophilum* becomes established in new sites. Nothing is known about the species' seed production or seed dispersal. There are no known dispersal adaptations of the seeds or fruit of *T. heliophilum*. *Thalictrum heliophilum* is probably dispersed by gravity, precipitation, and wind (O'Kane 1987). As the seeds fall from the plants, they may be covered by soil moving because of gravity or water, or they may be lodged in cracks in the shale (O'Kane 1987). As a rhizomatous species, *T. heliophilum* may also disperse as rhizomes break off and are moved by water or gravity.

Phenotypic plasticity

Thalictrum heliophilum is not known to exhibit a great degree of phenotypic plasticity. Plants probably vary in size, stature, and reproductive effort due to year-to-year variations in climate.

Mycorrhizal relationships

Roots of *Thalictrum heliophilum* have not been assayed for the presence of mycorrhizal symbionts.

Hybridization

Hybridization has not been documented in *Thalictrum heliophilum*. O'Kane (1987) reports that it does not grow near any of its congeners. However, it is possible *that T. heliophilum* could exchange pollen with *T. fendleri*, a close relative that grows in the same general area, and gene flow between the two species is possible. However, *T. foetidum*, a Eurasian species, may be synonymous with *T. heliophilum*, and *T. foetidum* is not a close relative of any of the native American species of *Thalictrum* (Weber personal communication 2006).

Demography

O'Kane (1987) noted that all age classes appear to be present at most occurrences, seedlings are abundant where the plants are abundant, and plants appear to produce numerous fruits. However, there have been no formal studies of the demographics of *Thalictrum heliophilum*. Nothing is known about the specifics of annual seed production, seed viability, or dormancy, or other factors related to survival or mortality (O'Kane 1987). Longevity of seeds and plants is not known. Some authors have speculated that the plants may be long-lived because they have large root stocks (O'Kane 1987), and they may therefore live up to 40 years or more (USDA Forest Service 2002b). However, we did not find any evidence to support these claims, and many short-lived plant species (e.g., carrots) also have large roots.

Annual precipitation is likely to be one of the primary determinants of seedling establishment, survival, and seed production in *Thalictrum heliophilum*. Although relatively wet years may set the stage for an increase in overall numbers of plants, this has not been documented. Mortality is probably highest in hot, dry years. Shifting substrates and rock falls may also be major sources of natural mortality (O'Kane 1987).

The lifespan of *Thalictrum heliophilum* has not yet been determined. There are no data regarding the proportion of individuals within a population that reproduce in a given year. In favorable years, many or most female plants probably set seed.

No Population Viability Analysis (PVA) has been performed for *Thalictrum heliophilum*. Apparently, there has never been a PVA of any member of the genus *Thalictrum* from which inferences could be drawn for this report. *Thalictrum cooleyi* is federally listed as Endangered (U.S. Fish and Wildlife Service 2005), but a PVA of this species has not been conducted (U.S. Fish and Wildlife Service 1994).

Maintaining genetic integrity and eliminating inbreeding and outbreeding depression are important management considerations for *Thalictrum heliophilum*. As an outcrossing species, it is vulnerable to inbreeding depression in small populations. Given the moderate degree of disturbance and fragmentation of the habitat for *T. heliophilum*, it is possible that genetic diversity is being lost. Maintaining distinct genetic populations and natural levels of gene flow are important for its conservation.

Spatial arrangement of male and female plants may also be pertinent to potential for interbreeding (U.S. Fish and Wildlife Service 1994). An important consequence of dioecy in plants is the effect of the sex ratio on effective population size (Hartl and Clark 1989). For dioecious species, such as *Thalictrum heliophilum*, any variance of the sex ratio from an equal number of male and female plants reduces the effective population size. A smaller effective population size increases the potential for inbreeding depression and genetic drift. The ratio of male to female plants has not been reported at any occurrence of *T. heliophilum*.

Community ecology

Thalictrum heliophilum grows on very sparsely vegetated talus and scree slopes within *Pseudotsuga menziesii* (Douglas-fir) or *Pinus edulis* (pinyon pine) - *Juniperus osteosperma* (Utah juniper) woodlands, or mixed mountain shrublands that may include *Quercus gambelii* (Gambel oak), *Cercocarpus montanus* (mountain mahogany), *Holodiscus dumosus* (rock spiraea), *Prunus virginiana* (chokecherry), *Amelanchier utahensis* (Utah serviceberry), *A. alnifolia* (Saskatoon serviceberry), *Ribes cereum* (wax currant), mountain snowberry, *Artemisia tridentata* ssp. *vaseyana* (mountain sagebrush), or *A. tridentata* ssp. *wyomingensis* (Wyoming sagebrush). The subspecies of *A. tridentata* can be extremely difficult to differentiate. **Table 2** is a complete list of all 53 vascular plants that have been documented with *T. heliophilum*.

Thalictrum heliophilum is found on shale barrens where the cover of bare ground and rock is between 80 and 95 percent (O'Kane 1987, Colorado Natural Heritage Program 2005). *Thalictrum heliophilum* is one of the dominant species where it is found, comprising about 50 percent of the relative cover (O'Kane 1987, Colorado Natural Heritage Program 2005).

Herbivores

Field observations of *Thalictrum heliophilum* by O'Kane (1987) and others (Colorado Natural Heritage Program 2005) recorded no evidence of herbivores, predators, pests, parasites, or disease. The specific responses of *T. heliophilum* to herbivore damage have not been investigated, but deer or elk may occasionally browse the plants (O'Kane 1987). Rocky Mountain bighorn sheep occur at the USFS occurrence (Carsey 1996), but it is not known if the sheep browse *T. heliophilum*.

Competitors

There has been no formal study of the community ecology and interspecific relationships of *Thalictrum heliophilum*. As a habitat specialist of Green River shale barrens, *T. heliophilum* may be a poor competitor. This may leave it vulnerable to negative impacts from introduced species. For a discussion of the threats to *T. heliophilum* from exotic species, please see the Threats section of this document.

CONSERVATION

Threats

Potential threats to the persistence of *Thalictrum heliophilum* include oil shale mining, oil and gas development, exotic species invasions, grazing by wild ungulates, effects of small population size, and climate change. More complete information on the

biology and ecology of this species will help with understanding the magnitude of these threats, and it may reveal other threats. The time frame within which these factors affect occurrences of *T. heliophilum* is unknown. Assessment of threats to this species will be an important component of inventories and monitoring. Recreation and domestic livestock grazing are not considered threats because of the steep, unstable, and inaccessible slopes that comprise the species' habitat (O'Kane 1987). This could change as oil and gas development and oil shale mining continue and create more road access to habitat. Recreational use is minimal at the USFS occurrence (Carsey 1996, Johnston personal communication 2005).

Several species of *Thalictrum* are used as ornamentals (Park and Festerling 1997), and seeds of *T. heliophilum* are available through Rocky Mountain Rare Plants (Rocky Mountain Rare Plants 2005). They report that *T. heliophilum* "looks spectacular in a sunny crevice of a native rock garden." We were unable to determine whether the seeds were collected from the wild or if plants are cultivated for seeds. Overall, there is little evidence to suggest that these activities threaten *T. heliophilum*.

Numerous alkaloids have been isolated from other members of the genus *Thalictrum* that have pharmacologic potential (Park and Festerling 1997). *Thalictrum* alkaloids that exhibit antimicrobial activity have been identified while others inhibit growth of tumors or lower blood pressure in mammals (Park and Festerling 1997). No examples of *T. heliophilum* being used for these purposes have been documented.

It is possible that in spite of the potential threats detailed below, the population of *Thalictrum heliophilum* is adequate to survive the impacts. However, the cumulative effects of all potential threats must also be considered. Few protective measures are in place to assure persistence of this species in the context of human population growth and future resource demands. Research is warranted to determine the extent of these activities and how they combine to affect the distribution and abundance of *T. heliophilum*.

Oil shale mining

The habitat for *Thalictrum heliophilum* contains high-grade oil shale (hydrocarbon) deposits. The Parachute Creek Member of the Green River Formation is reported to have the best deposits of oil shale known in the world (O'Kane 1987), and is considered to be a major potential source of oil in the United States (O'Kane and Anderson 1987, Williamson 1999, Center for Native Ecosystems et al. 2005). Oil shale can be mined and refined into petroleum products; with current technologies, millions of tons of shale must be mined each year to make the process economically feasible, even where the oil shale is richest in hydrocarbons (Colorado Native Plant Society 1997).

Current federal energy policy targets a reduction in U.S. dependence on foreign oil by a strategy that includes increasing domestic energy production (National Energy Policy Development Group 2001). This policy increases pressure to use public and private lands to meet national demands for petroleum products. As a result, oil companies, public land management agencies, and lawmakers are giving increased consideration to oil shale mining, despite its considerable environmental impacts (Center for Native Ecosystems et al. 2005, Talhelm 2005).

Oil shale mining and processing impacts include open pit mines, dynamiting, injecting superheated water into the ground, spent shale disposal sites, road construction, spraying of herbicides along roads, test drilling, test pits, pipelines, increased erosion due to vegetation removal, and increased air pollution (O'Kane 1987, Center for Native Ecosystems et al. 2005). These activities could cause population fragmentation, habitat destruction, and habitat degradation, such as introductions of non-native plant species.

Current technology requires a great deal of water to process the oil shale. Although oil shale research and extraction are fairly minimal at this time, oil companies (e.g., Getty, Chevron, and OXY) continue to hold water rights permits for oil shale mining in Garfield County (Center for Native Ecosystems et al. 2005). In order to hold the water rights, these companies must apply every six years to the water court and show that the proposed projects involving the water uses can and will be completed within a reasonable amount of time (Center for Native Ecosystems et al. 2005). Depending on oil prices and technological advances for extraction, activity could resume at a very large scale, and the impacts from even small-scale oil shale mining could be severe for *Thalictrum heliophilum*, depending on its proximity to occurrences and/or potential habitat.

In the 1980s, several oil companies spent billions of dollars developing oil shale mining technology (Williamson 1999). The town of Battlement Mesa developed largely to support this industry, and other local towns (Parachute, Rifle, Craig, and Silt) struggled to keep up with the population growth. Housing

developments, roads, and water systems were developed, largely funded by the oil companies. In 1982, the oil companies abandoned mining activities because they were not economically viable. This was partially due to a fall in the market price of oil (USDI Bureau of Land Management 1996). If oil shale development resumes, human developments and infrastructures would likely follow as they did in the early 1980s.

Shell Oil Company has been conducting experimental drilling and oil shale processing since 1996 (Center for Native Ecosystems et al. 2005, Scheck personal communication 2005). They are pursuing new methods for extraction that are more economically viable. The federal government is also interested in supporting experimental oil shale research and development on public lands (Scheck personal communication 2005).

Sixteen of the 18 known occurrences of *Thalictrum heliophilum* could be affected by oil shale mining and associated infrastructures, such as roads and pipelines (Colorado Natural Heritage Program 2005). There is no protection of the species on private lands, and the Resource Management Plan for the BLM, White River Resource Area states that an objective is "to provide for a prudent and planned future leasing and development program for the oil shale resource" (USDI Bureau of Land Management 1996). The South Cathedral Bluffs ACEC has a "no surface occupancy" stipulation (USDI Bureau of Land Management 1996), which should afford adequate protection to *T. heliophilum* at that location. Oil shale development does not threaten the occurrence on National Forest System land at Dry Fork Kimball Creek (Johnston personal communication 2005).

Oil and gas development

Rich deposits of oil and natural gas also underlie the habitat that supports *Thalictrum heliophilum*. In recent years, oil and gas development and well density have increased dramatically in western Colorado, driven by higher prices and by the current federal government's energy policy. An oil and gas well location map for Colorado (Colorado Oil and Gas Conservation Commission 2004) shows that all 18 *T. heliophilum* occurrences are within 3 miles of an existing well.

Oil and gas development involves associated infrastructure, such as roads and pipelines. Construction and maintenance of this infrastructure are occurring on BLM and private lands. Energy development can cause population fragmentation, habitat destruction, and habitat degradation, such as introductions of non-native plant species and alteration of surface hydrology (Center for Native Ecosystems et al. 2005). Oil and gas development requires an extremely high density of roads, opening previous inaccessible areas to off-road vehicle use (Center for Native Ecosystems et al. 2005). Impacts to *Thalictrum heliophilum* depend on the proximity of the activities to occurrences and/or potential habitat. Well pads would probably not be placed on the steep slopes that support occurrences of *T. heliophilum*, but roads that would be built to access drill sites could threaten this species' habitat (Scheck personal communication 2005).

Oil and gas development and associated infrastructures could affect 16 of the 18 known occurrences of *Thalictrum heliophilum* (Colorado Natural Heritage Program 2005). There is no protection on private lands, and the Resource Management Plan for the BLM's White River Resource Area states that an objective is "to make federal oil and gas resources available for leasing and development in a manner that provides reasonable protection for other resource values" (USDI Bureau of Land Management 1996). The South Cathedral Bluffs ACEC has a no surface occupancy stipulation (USDI Bureau of Land Management 1996), which should afford adequate protection to *T. heliophilum* at that location. Oil and gas development does not threaten the occurrence on National Forest System land at Dry Fork Kimball Creek at this time (Johnston personal communication 2005).

Exotic species invasions

Although no exotic species have been documented in direct association with *Thalictrum heliophilum* (Colorado Natural Heritage Program 2005), a few aggressive weeds pose a potential threat to this species and its habitat. To date, plants that are considered noxious weeds that have been reported in close proximity to occurrences of *T. heliophilum* include yellow sweet clover (*Melilotus officinalis*), cheatgrass (*Bromus tectorum*), houndstongue (*Cynoglossum officinale*), and musk thistle (*Carduus nutans*; Carsey 1996, Colorado Natural Heritage Program 2005, Scheck personal communication 2005). These noxious weeds are likely to be spread by activities associated with resource extraction activities and infrastructure, including roads and pipelines. Without close regulation, reclamation and re-seeding following mining and oil and gas development could introduce these or other problematic species.

The proximity of invasive species to populations of *Thalictrum heliophilum* presents the risk that if the habitat is disturbed, the invasive species could expand into undisturbed habitat. In these situations, invasive species could outcompete existing populations of *T. heliophilum* or prevent establishment of the plant in potential habitat. Noxious weeds may compete with *T. heliophilum* for water and other resources as well as modify its habitat.

The best strategy for protection of *Thalictrum heliophilum* is to prevent the introduction of these non-natives by carefully monitoring occurrences for the presence of noxious weeds. If weeds are detected, a weed management plan should be implemented immediately. The BLM, State of Colorado, and local counties are striving to prevent the spread of noxious weeds. However, areas that support *T. heliophilum* would not necessarily be priority areas for weed control (U.S. Department of the Interior 1996).

Small population size

Thalictrum heliophilum may be vulnerable because of its small population size. The estimated global population is approximately 156,735 individuals (**Table 1**; Colorado Natural Heritage Program 2005). Although more rigorous population estimates are needed, the potential for catastrophes, such as severe drought, disease or pest outbreak, and severe local surface disturbances, render occurrences of this species vulnerable to local extirpations. The degree to which *T. heliophilum* can survive bad years or can re-colonize disturbed areas will depend largely on how long individual plants can persist or remain dormant as seeds or rhizomes, which is not known.

Small occurrences may have lower genetic diversity than larger occurrences and therefore may be more vulnerable to extirpation from natural or human-caused disturbances (O'Kane 1987, Huenneke 1991). Small populations may also be less able to adapt to a changing environment and to respond to pressures such as pests and disease (Barrett and Kohn 1991). Genetic drift has a particularly strong influence on populations that are small and isolated, and genetic variability is lost even more quickly, which makes them more prone to local extirpations (Barrett and Kohn 1991).

The small size of many populations of *Thalictrum heliophilum* makes inbreeding depression, loss of genetic diversity, genetic drift, and population fragmentation important issues for the conservation of this species. Little is known about the population genetics of *T. heliophilum*. The degree of connectedness among occurrences is not known, but current knowledge of the species' distribution suggests that many of the occurrences are genetically isolated from each other.

Overall, the small number of occurrences suggests that *Thalictrum heliophilum* is imperiled. This species is very poorly understood, which is a liability because well-intended conservation actions cannot be as effective when basic information is not available. Five occurrences apparently have not been visited and assessed in more than 20 years. This adds a great deal of uncertainty to any assessment using these data.

Grazing by wild ungulates

Rocky Mountain bighorn sheep, mule deer, and elk use *Thalictrum heliophilum* habitat, and in some instances, the use is described as heavy (Carsey 1996, USDA Forest Service 2002b, Colorado Natural Heritage Program 2005). Wild ungulate use is described as being the greatest habitat modification occurring at the North Fork Kimball Creek occurrence on National Forest System lands (USDA Forest Service 2002b, Johnston personal communication 2005). Reports state that the animals do not stay for long in any one place; they are traveling across the slope, but the high numbers may cause problems by making the substrate more unstable (USDA Forest Service 2002b). Incidental browsing may be an issue, but this is not documented. Further research is warranted to determine the effects of the current levels of sheep, deer, and elk travel on populations of *T. heliophilum*.

Global climate change

Global climate change is likely to have wide-ranging effects. Projections based on current atmospheric CO_2 trends suggest that average temperatures will increase while precipitation will decrease in Colorado (Manabe and Wetherald 1986). This may have significant effects on nutrient cycling, vapor pressure gradients, and a suite of other environmental variables. Temperature increase could cause vegetation zones to climb 350 feet in elevation for every degree Fahrenheit of warming (U.S. Environmental Protection Agency 1997). Because it already inhabits the higher elevations available in the Piceance Basin, *Thalictrum heliophilum* has limited options for upward migration in the face of warming temperatures. Because the habitat for *T. heliophilum* is already xeric, lower soil moistures in the growing season induced by decreased precipitation

could have serious impacts. For example, a drying trend could force *T. heliophilum* into seepage areas, where competition from other plant species would be greater.

Conservation Status of Thalictrum heliophilum in Region 2

Is distribution or abundance declining in all or part of its range in Region 2?

Long-term data that would show trends in the distribution or abundance of *Thalictrum heliophilum* across its range are lacking. Because the pre-settlement population size of *T. heliophilum* is unknown, it is difficult to assess the effects of mining, infrastructure, and management regimes on abundance. Extreme forms of disturbance such as strip mining would extirpate occurrences. With so many different landowners and land managers within the distribution of *T. heliophilum*, it is likely that management of some properties is not compatible with the persistence of the species while other properties are managed appropriately. Inventory and monitoring studies will help to determine the current population trend of this species.

Do habitats vary in their capacity to support this species?

Habitats where *Thalictrum heliophilum* is found appear to vary in their capacity to support it. However, many apparently suitable sites do not support *T. heliophilum*, which makes it difficult to assess habitat quality; these sites may be highly suitable but simply unoccupied. Much remains unknown about the nature of the habitat to which *T. heliophilum* is adapted. Refinements of our understanding of the relationships between *T. heliophilum* and its habitat will be possible with additional research.

Vulnerability due to life history and ecology

The unfortunate overlap of *Thalictrum heliophilum*'s narrow range with high-quality deposits of petroleum resources is the primary source of its vulnerability. As a narrowly restricted species, *T. heliophilum* may be somewhat vulnerable to environmental stochasticity, at least to factors operating on a regional scale. The degree to which it can survive bad years will depend largely on how long individual plants can persist or remain dormant as seeds or rhizomes, and this information is not known.

Evidence of populations in Region 2 at risk

Oil shale mining and oil and gas development have the potential to affect nearly all of the global range of *Thalictrum heliophilum*, and there are no provisions to ensure the long-term viability of this species in the face of these threats. There are only three small areas that include *T. heliophilum* and offer some level of protection, the South Cathedral Bluffs and East Douglas Creek ACECs managed by the BLM, and Dry Fork Kimball Creek managed by the USFS. A forest management plan developed by the White River National Forest specifies that each known occurrence of *T. heliophilum* on the forest be monitored every five years, and that surveys for this species be conducted prior to any activities that could harm it (USDA Forest Service 2002b).

The total population of *Thalictrum heliophilum* is relatively small, with an estimated 156,735 plants documented. While populations of this size are probably viable, natural isolation of occurrences and fragmentation of its habitat suggest that gene flow throughout the population may be limited, leading to smaller effective population sizes.

Management of Thalictrum heliophilum in Region 2

Implications and potential conservation elements

The available data suggest that *Thalictrum heliophilum* is a narrowly endemic species that is vulnerable due to small, isolated occurrences and threats to its habitat. Conservation easements and protective management designations offer the best chance for the conservation of this species. Given its restricted range and threats to its habitat, management policies must take steps to ensure that this species persists. Without proactive efforts to conserve it, *T. heliophilum* may eventually warrant listing under the Endangered Species Act.

Although the habitat for *Thalictrum heliophilum* requires prompt protection from severe disturbances such as oil shale and oil and gas development, the occurrences do not appear to require direct management interventions at this time (e.g., weed control, restoration). Placing this species on the BLM sensitive species list or federal listing as Threatened under the Endangered Species Act would add some needed protection for this species and its habitat.

Desired environmental conditions for *Thalictrum heliophilum* include sufficiently large areas where the natural ecosystem processes on which it depends can occur, permitting it to persist unimpeded by human activities and their secondary effects, such as weeds. From a functional standpoint, ecosystem processes on which *T. heliophilum* depends appear to remain intact in all known occurrences. Whether this will remain true with accelerating oil shale and oil and gas development is uncertain. Although *T. heliophilum* populations are apparently viable at present, the natural ecosystems and ecosystem processes could be altered, and the habitat destroyed or fragmented. Studies of the ecology and distribution of *T. heliophilum* will help to develop effective approaches to management and conservation. Given the rarity and potential vulnerability of this species, conserving the highest quality occurrences is a high priority for biodiversity conservation.

A thoughtful assessment of current management practices on lands occupied by *Thalictrum heliophilum* is likely to identify opportunities for change that would be inexpensive and have minimal impacts on the livelihood and routines of local residents, managers, and permittees, while conferring substantial benefits on *T. heliophilum*.

Tools and practices

Species inventory

Species inventory is a high priority for *Thalictrum heliophilum*. Collecting baseline information and developing a detailed map of the known distribution and abundance of this species will provide a starting point from which population trend can be assessed. During several concerted efforts to find *T. heliophilum*, new occurrences were identified (Colorado Natural Heritage Program 2005). This suggests that further searching could yield other yet undiscovered occurrences. Species inventories are simple, inexpensive, and effective, and are necessary for developing an understanding of the target species sufficient for developing a monitoring program.

Thalictrum heliophilum is a relatively conspicuous species, and, as long as it is flowering, is not difficult to distinguish from other local species or other species of *Thalictrum*. It also tends to grow in open habitats, which makes it easy to find. Field crews could be quickly taught to recognize it. Searching for *T. heliophilum* is complicated by the need to obtain permission to enter private land throughout its known range, and locating this species can be difficult in dry years when fewer plants produce flowers.

Areas with the highest probability of new occurrences are shale barrens of the Parachute Creek Member of Green River Formation within the range of the known occurrences. Many areas within the known range of *Thalictrum heliophilum* remain to be searched because of the difficulties in accessing remote areas. Barry Johnston (personal communication 2005) reports that there are extensive areas of the Parachute Creek Member on Battlement Mesa (near the Dry Fork Kimball Creek occurrence) that have not been searched for *T. heliophilum*. The Parachute Creek Member is well-mapped (Coles personal communication 2006), so it should be a straightforward exercise to locate this layer and search the areas for *T. heliophilum*.

Habitat inventory

The Colorado Natural Heritage Program routinely uses aerial photography and topographic, soil, and geology maps to refine search areas when conducting inventories of large areas. This approach has been highly effective in Colorado and elsewhere. It is most effective for species about which we have basic knowledge of its habitat specificity from which distribution patterns and potential search areas can be deduced.

Modeling habitat based on the physiognomy of known occurrences could aid searches for *Thalictrum heliophilum*. The intersection of topography, geologic substrate, and vegetation could be used to generate a map of a probabilistic surface showing the likelihood of the presence of *T. heliophilum* in given locations. This would be a valuable tool for guiding and focusing future searches. Dr. Tom Stohlgren's group at the Natural Resource Ecology Laboratory (NREL) at Colorado State University has used these techniques to model weed invasion probabilities in native ecosystems (Stohlgren et al. 2003) and will be using such techniques to model potential rare plant habitat in the near future (Stohlgren personal communication 2002).

Population monitoring

There are three levels of population monitoring available to land managers. In order of effort, least to most, they are qualitative monitoring (including abundance estimates and photo points), population trend monitoring (sampling in plots), and demographic monitoring (tracking individually tagged plants). Although demographic data would be helpful because

so little is known about the species, the other two levels are less resource-intensive and probably more realistic for agencies to undertake.

Monitoring *Thalictrum heliophilum* is difficult because of the steep, unstable habitat in which it grows. Researchers traversing the slopes inevitably dislodge loose shale that then slides down to cover or damage plants. Traversing the steep slopes is dangerous and time consuming. In addition, distinguishing individual *T. heliophilum* plants can be impossible because it spreads by rhizomes. Given these difficulties, presence/absence monitoring is recommended for most occurrences of *T. heliophilum*, especially where no disturbance is occurring or planned. Researchers could record estimates of abundance and occupied area, and make notes of problems such as weed invasions or other disturbances. Adding a photo point component to this work following recommendations offered in Elzinga et al. (1998) could add valuable qualitative information. A handbook on photo point monitoring (Hall 2002) offers detailed instructions on establishing photo point monitoring plots.

A population trend monitoring program for *Thalictrum heliophilum* would begin by targeting a subset of the known occurrences, and other occurrences could be added to the program as necessary. The best sampling design would probably be to establish permanent macroplots, inside which plants are sampled in long narrow quadrats arranged perpendicularly to plant density gradients, so that each quadrat includes the dense and sparse ends of the gradient (Coles personal communication 2006). Permanent quadrats would be preferable to temporary quadrats since the plants are relatively immobile. Numbers of quadrats necessary would depend on the degree of precision desired.

Estimating cover and/or abundance of associated species within the quadrats could permit the investigation of interspecific relationships through ordination or other statistical techniques. In very sparsely vegetated plots, this can be difficult, but it can be done accurately using appropriate cover classes or subdivided quadrat frames.

Understanding environmental constraints on *Thalictrum heliophilum* would facilitate the management of this species. Gathering data on edaphic characteristics (soil moisture, texture, chemistry) from the permanent plots described above would permit the canonical analysis of species-environment relationships. These data would facilitate hypothesis generation for further studies of the ecology of this species.

Monitoring interactions with potential pollinators could be done by expanding on the methods employed by Spackman Panjabi (2004). Suitable methods for monitoring pollinators are also discussed in Kearns and Inouye (1993). Measuring seed production will require a visit later in the summer after fruit set. In any monitoring study undertaken for this species, it will be important to define *a priori* the changes the sampling regime intends to detect, and the management actions that will follow from the results (Schemske et al. 1994, Elzinga et al. 1998).

Monitoring sites under a variety of land use scenarios (e.g., resource extraction activities and associated infrastructure) will help to identify appropriate management practices for *Thalictrum heliophilum* and to understand its population dynamics and structure. However, it will be difficult to ascribe changes in populations or plants to the effects of management unless there are controls sampled simultaneously and without many replicates of both treated and untreated sites.

Because of potential annual variability in reproductive effort, resampling of monitoring plots will be necessary every year to gain insight into the population dynamics of *Thalictrum heliophilum*. The best time to monitor this species is June through July when most plants are flowering.

Habitat monitoring

Habitat monitoring should be conducted concurrently with population monitoring in occupied habitat. Documenting habitat attributes, disturbance regime, and associated species will augment our present understanding of the species' habitat requirements and management needs. These fields could be incorporated into the forms used for population monitoring. If carefully selected environmental variables are quantified during monitoring, they may help explain observations of population change. Habitat monitoring of known occurrences will alert managers of new impacts such as weed infestations and damage from human disturbance. Evidence of current land use practices and management is important to document while monitoring populations. Making special note of signs of degradation from recreational or other uses may help managers prevent serious degradation by implementing changes in the management prescription.

Observer bias can be a significant problem with habitat monitoring (Elzinga et al. 1998) unless field crews are trained in the consistent and accurate

estimation of species cover. Habitat monitoring is usually better at identifying new impacts than at tracking change in existing impacts. To assess trampling impacts, using photographs of impacts to train field crews will help them to consistently rate the severity of the impact.

The use of photopoints for habitat monitoring is described in Elzinga et al. (1998). This is a powerful technique that can be done quickly in the field. Although it does not provide detailed cover or abundance data, it can help to explain patterns observed in quantitative data.

Beneficial management actions

The establishment of areas to be managed for the conservation of *Thalictrum heliophilum* is the best conservation strategy for this species. As resource extraction and human population increase within its range, occurrences of *T. heliophilum* could be lost and its habitat will become increasingly fragmented. Conservation easements, fee purchase, and other land trust activities are useful conservation tools to protect occurrences on private land. Although this species does not occur on any existing conservation easements, there are many opportunities for county governments or other entities to purchase lands that support occurrences of *T. heliophilum*. Purchasing conservation easements, even on small properties, may confer significant benefits to the conservation of *T. heliophilum*. Land exchanges that bring sites on private land into federal ownership would also be a useful conservation tool.

Management practices that reduce the impacts from resource extraction and other activities on occurrences of *Thalictrum heliophilum* are likely to contribute greatly to the achievement of conservation goals for this species. For example, no-surface-occupancy, re-routing or closing trails or roads, and limiting off-road vehicle use are all potential conservation tools at the disposal of the USFS and other land management agencies.

Management strategies that prevent weed infestations in *Thalictrum heliophilum* habitats will benefit the species. Weed control practices, on the other hand, have the potential to affect *T. heliophilum* negatively and it would be best to avoid herbicide use within occurrences of *T. heliophilum*. The Colorado Natural Heritage Program can provide accurate data on the distribution of this species to assist with avoiding impacts to occurrences. Clearances of areas in question by someone who is familiar with *T. heliophilum* may also be necessary in certain situations.

There have been no active management efforts on behalf of *Thalictrum heliophilum* habitat or populations. Inventories and monitoring studies would be highly beneficial. Identifying high quality occurrences with large populations in intact landscapes will help managers to prioritize conservation efforts. Much suitable habitat within the range of *T. heliophilum* remains to be searched.

Seed banking

No seeds or genetic material are currently in storage for *Thalictrum heliophilum* at the National Center for Genetic Resource Preservation (Miller personal communication 2003). It is not among the National Collection of Endangered Plants maintained by the Center for Plant Conservation (Center for Plant Conservation 2005). Collection of seeds for long-term storage will be useful if restoration becomes necessary. The Denver Botanic Garden grows *T. heliophilum* in their Endangered Species garden (Grant personal communication 2005).

Information Needs

Distribution

Although inventories would likely identify new locations for *Thalictrum heliophilum*, the general distribution of this species is well known. Surveys are unlikely to find many new occurrences or extend the global range. Research focusing on the management and conservation of known occurrences should proceed concurrently with seeking new occurrences.

Life cycle, habitat, and population trend

Studies of *Thalictrum heliophilum* are needed to understand its life history and population ecology. Little is known about *T. heliophilum* seed production, seed dispersal, seed dormancy, germination requirements, seedling establishment and vigor, or longevity of plants.

The habitat for *Thalictrum heliophilum* has been described, but the nature of its habitat and its response to natural disturbance are poorly understood. Being able to identify suitable habitat is important for the conservation and management of *T. heliophilum*. Autecological research is needed to refine our definition

of appropriate habitat and to facilitate effective habitat monitoring and conservation stewardship of this species. The population trend of *T. heliophilum* is not known, and it may be difficult to quantify without many years of detailed monitoring data.

Response to change

Rates of reproduction and establishment and the effects of environmental variation on these parameters have not been investigated in *Thalictrum heliophilum*. Without this information, the effects of various management options cannot be assessed during project planning. Understanding the specific responses of *T. heliophilum* to disturbance is important for determining appropriate management practices.

Metapopulation dynamics

No research exists documenting the population ecology of *Thalictrum heliophilum*, and the importance of metapopulation structure and dynamics to its long-term persistence at local or regional scales is unknown. Migration, extinction, and colonization rates are unknown for *T. heliophilum*. Baseline population dynamics and viability must first be determined.

Demography

Only the broadest generalizations can be made regarding the demography of *Thalictrum heliophilum*. There is no rigorous population estimate available for this species. Growth and survival rates are unknown, and the rate of reproduction is poorly understood. Short-term demographic studies often provide misleading guidance for conservation purposes, so complementary information, such as historical data and experimental manipulations, should be included if possible (Lindborg and Ehrlén 2002).

Restoration methods

There have been no known attempts to restore habitat or occurrences of *Thalictrum heliophilum*; therefore, there is no applied research from which to draw in developing a potential restoration program. It is likely that *T. heliophilum* would respond well to direct seeding or propagation in a greenhouse environment, but it may be difficult to transfer plants successfully into a natural or restored setting. O'Kane (1988) reported that oil companies have used *T. heliophilum* for revegetation projects with success. The details of how the plants were introduced to the reclamation sites are not known.

Research priorities for Region 2

Inventories are needed to locate as many occurrences of *Thalictrum heliophilum* as possible. Expanding the boundaries of known occurrences, identifying new occurrences within the known range, and searching Green River Shale barrens outside of this range are the best first steps toward completing a picture *T. heliophilum*'s distribution. Targeted searches when plants are in flower (June through July) in suitable habitat will help to confirm the distribution and abundance of this species and may identify opportunities for its conservation. Identifying large, healthy occurrences on properties where landowners are interested in establishing protective land designations or easements is needed so that conservation of *T. heliophilum* can begin. Identifying robust occurrences in natural settings is important for setting conservation targets and priorities. Collecting detailed notes on associated species, habitat, geology, and soil conditions will help in developing a search image and determining best management practices. Documenting threats and visible impacts to *T. heliophilum* will help define conservation strategies and will help managers act to mitigate threats.

The role of disturbance in the autecology of *Thalictrum heliophilum* remains poorly understood. An understanding of the specific tolerances of *T. heliophilum* to different human and natural disturbance regimes will assist with developing conservation strategies and management plans by determining the types of disturbance most likely to impact it negatively.

Information gleaned from studies of the physiological and community ecology of *Thalictrum heliophilum* will be valuable in the event that an occurrence needs to be restored, and it will help to determine biotic and abiotic factors that contribute to its survival. Understanding the plant-environment relationship for *T. heliophilum* will be helpful in clarifying the coping strategies that this species employs, and it will help to model its potential distribution. Genetic studies will help resolve the question of whether *T. heliophilum* and *T. foetidum* are synonymous.

DEFINITIONS

Abiotic – non-living, devoid of life (Allaby 1998)

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

Autecology – the ecology of individual organisms and populations (Allaby 1998)

Cauline – borne on the stem, above ground; refers to leaves; opposed to basal (Weber and Wittmann 2001)

Channer – A thin, flat fragment of sandstone, shale, slate, limestone, or schist as much as 6 inches along the longest axis.

Dioecious – bearing the staminate flowers on one individual and the carpellate on another of the same species (Weber and Wittmann 2001)

Edaphic – of the soil or influenced by the soil (Allaby 1998)

Glaucous – having a bloom or whitish covering, usually waxy, on the stem or leaf; this may disappear if the plants are dried with heat (Weber and Wittmann 2001)

Graminoid – grass-like

Isotype – a duplicate specimen of the holotype, or type specimen

Lanceolate – long and narrow, but broadest at the base (Weber and Wittmann 2001)

Lysimetry – estimation of evapotranspiration

Outcrossing – fertilization involving pollen and ovules from different flowers on genetically distinct plants; synonymous with xenogamy (Allaby 1998)

Panicle – a repeatedly branched inflorescence with pedicelled flowers (Weber and Wittmann 2001)

Pedicel – the stalk of a single flower

Pistillate – having only carpels, no stamens

Potential Conservation Area (PCA) – a best estimate of the primary area supporting the long-term survival of targeted species or natural communities; PCAs are circumscribed for planning purposes only (Colorado Natural Heritage Program Site Committee 2001)

Quadrat – a basic sampling unit of vegetation surveys (Allaby 1998)

Staminate – having stamens but not carpels

Taxon (plural taxa) – a group of organisms of any taxonomic rank, e.g., family, genus, or species (Allaby 1998)

Transect – a linear vegetation sampling method (Allaby 1998)

Tridentate – three-toothed

Imperilment Ranks used by natural heritage programs, natural heritage inventories, Natural Diversity Databases, and NatureServe.

Global imperilment (G) ranks are based on the range-wide status of a species. State-province imperilment (S) ranks are based on the status of a species in an individual state or province. State-province and Global ranks are denoted, respectively, with an "S" or a "G" followed by a character. **These ranks should not be interpreted as legal designations.**

G/S1	Critically imperiled globally/state-province because of rarity (5 or fewer occurrences in the world/state; or very few remaining individuals), or because of some factor of its biology making it especially vulnerable to extinction.
G/S2	Imperiled globally/state-province because of rarity (6 to 20 occurrences), or because of other factors demonstrably making it very vulnerable to extinction throughout its range.
G/S3	Vulnerable through its range or found locally in a restricted range (21 to 100 occurrences).
G/S4	Apparently secure globally/state-province, though it might be quite rare in parts of its range, especially at the periphery.
G/S5	Demonstrably secure globally, though it may be quite rare in parts of its range, especially at the periphery.
GX	Presumed extinct.
G#?	Indicates uncertainty about an assigned global rank.
G/SU	Unable to assign rank due to lack of available information.
GQ	Indicates uncertainty about taxonomic status.
G/SH	Historically known, but not verified for an extended period, usually.
G#T#	Trinomial rank (T) is used for subspecies or varieties. These taxa are ranked on the same criteria as G1-G5.
S#B	Refers to the breeding season imperilment of elements that are not permanent residents.
S#N	Refers to the non-breeding season imperilment of elements that are not permanent residents. Where no consistent location can be discerned for migrants or non-breeding populations, a rank of SZN is used.
SZ	Migrant whose occurrences are too irregular, transitory, and/or dispersed to be reliable identified, mapped, and protected.
SA	Accidental in the state or province.
SR	Reported to occur in the state or province, but unverified.
S?	Unranked. Some evidence that the species may be imperiled, but awaiting formal rarity ranking.

Notes: Where two numbers appear in a G or S rank (e.g., S2S3), the actual rank of the element falls between the two numbers.

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