Alpine Plant Community Trends on Elk Summer Range of Rocky Mountain National Park, Colorado: An Analysis of Existing Data

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Effects of Elk Herbivory on Alpine Plant Communities on the Elk Summer Range, Rocky Mountain National Park, Colorado—An Analysis of Existing Data

By Linda Zeigenfuss[1]

Abstract

The majority of the elk (*Cervus elaphus*) population of Rocky Mountain National Park in Colorado summer in the park's high-elevation alpine and subalpine meadows and willow krummholz. The park's population of white-tailed ptarmigan (*Lagopus leucurus altipetens*) depends on both dwarf and krummholz willows for food and cover. Concern about the effects of elk herbivory on these communities prompted the monitoring of 12 vegetation transects in these regions from 1971 to 1996. Over this 25-year period, data were collected on plant species cover and frequency and shrub heights. These data have not been statistically analyzed for trends in the measured variables over time to determine changes in species abundance. Krummholz willow species (*Salix planifolia, S. brachycarpa*) declined 17–20 percent in cover and about 25 centimeters in height over the study period. Graminoids (particularly *Deschampsia caespitosa, Carex*, and *Poa*) increased slightly from 1971 to 1996. No significant increases of nonnative plant species were observed. An increase in presence of bare ground over the 25-year period warrants continued measurement of these transects. Lack of good data on elk density, distribution, or use levels precludes correlating changes in plant species cover, frequency, or heights with elk population trends. I recommend development of a more rigorously designed monitoring program that includes these transects as well as others chosen on a random or stratified design and consistent measurement protocol and sampling intervals. Some method of quantifying elk use, either through measurement of plant utilization, pellet counts, or census-type surveys, would allow correlation of changes in plant species over time with changes in elk distribution and density on the park's alpine and subalpine regions.

Introduction

The elk (*Cervus elaphus*) population that winters along the eastern boundaries of Rocky Mountain National Park (RMNP) and in the Estes Valley of Colorado currently numbers around 2,200 elk. Approximately 75 percent of this population summers in the alpine and subalpine regions of the park. This population has been increasing in recent decades (Lubow and others, 2002). Approximately 150–200 elk have also been observed to winter at these high elevations and may be browsing alpine willow communities to a great extent during winter. Park management is concerned about the effects of large numbers of elk on alpine and subalpine willow and tundra

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communities located in the park's high central mountains (Stevens, 1980; Therese Johnson, Rocky Mountain National Park, oral commun., 2005). Alpine willow communities are crucial to the park's population of white-tailed ptarmigan (Braun and Rogers, 1971; Braun and others, 1976). State of Colorado biologists have reported declines in white-tailed ptarmigan (*Lagopus leucurus altipetens*) in core areas along Trail Ridge and have attributed the decline to willow habitat declines due to high densities of elk (Braun and others, 1991). Former park biologist David Stevens reported significant declines in willows at long-term sites monitored in the 1970s and 1980s (Stevens, 1993). Stevens' work, however, was limited in inference to those few plots he monitored and not to landscape scale.

White-tailed ptarmigan populations have declined about 55 percent during the period 1975-1999 in a study area on Trail Ridge in RMNP (Wang and others, 2002). This period of decline roughly corresponds to a period of substantial increase in the Estes Valley elk population (Lubow and others, 2002), which summers in the alpine/subalpine areas of the interior of RMNP. The elk increases were once thought to be related to the ptarmigan decline (Braun and others, 1991), but Wang and others (2002) found no correlation between the Rocky Mountain National Park/Estes Valley elk population size and the ptarmigan population growth rate. Elk, however, may still have a long-term, time-lag negative influence upon ptarmigan populations through slower decline in willow abundance due to the elk increases. Willows might take a decade or more to decline in response to overabundance of elk, and the Wang and others (2002) analysis did not search for time-lag effects.

Ptarmigan population cycles, however, may be correlated to weather. Willow communities may also be affected by changes in the climate, and climate records indicated a warming (+0.89°C) and drying (–101.4 mm annual precipitation) trend on the low-elevation winter range of the park from 1948 to 1997 (Singer and others, 1998). Similar climate change is likely occurring in the park's alpine regions. Average May and June temperatures recorded at Niwot Ridge Long-Term Ecological Research Site, 40 km south of the Trail Ridge area of RMNP, showed a significant increase of about 2°C over the 2 decades from 1976 to 1996 (Wang and others, 2002). While high levels of elk herbivory alone may not cause willow decline, herbivory coupled with climate changes may be contributing to decline of lower elevation willow communities in areas such as Yellowstone and Rocky Mountain National Parks (Wagner and others, 1995; Singer and others, 1998).

White-tailed ptarmigan are obligate habitat specialists that require willows. White-tailed ptarmigan may use two height strata of willows. Short, often dwarf, willows or willows only 7–24 cm in height are preferred during the summer months (Frederick and Gutierrez, 1992) and during the winter months, when these areas are blown largely snow free (Braun and others, 1976; Francis Singer, U.S. Geological Survey, oral commun., 2003). Taller shrub willows (>90 cm), more typically found at or below the treeline, are avoided when there is minimal or no snow cover (Frederick and Gutierrez, 1992), but crowns of taller willows may become more accessible when snows get deeper and the birds gain access to buds and smaller shoots of the crown by walking on deeper snow (Braun and others, 1976; Francis Singer, U.S. Geological Survey, oral commun., 2003).

Vegetation data were collected on 12 transects in subalpine krummholz and alpine tundra plant communities in RMNP at varying intervals over a 25-year period from 1971 to 1996. These data were never subjected to any rigorous statistical analysis to detect trends over that time period. Data that were collected include plant cover and willow height and cover. No data were collected on percent leader use of willows by elk or elk fecal pellet counts; therefore, one could not correlate trends observed in plant cover and shrub heights to any trends in elk use or increased utilization of willows. Therefore, any conclusions that changes in alpine and subalpine vegetation types are the effect of increased levels of elk herbivory are speculative. The study objectives will address the following questions:

1. What was the trend in plant cover, heights, and species composition from 1971 to 1996?
2. Was there a decline in alpine/subalpine willow heights that may have indicated decreasing habitat for white-tailed ptarmigan over the 25-year study period?

Study Area

Description of the study area has been taken from Stevens (1980) and Hobbs and others (1982). Subalpine krummholz was defined as the ecotone between the subalpine forest and alpine tundra occurring at about 3,300–3,600 m elevation in Rocky Mountain National Park. It is characterized by an intermingling of species from both habitats. Primary plant species include stunted Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*), often mixed with willows (*Salix planifolia*, *S. glauca*, *S. brachycarpa*) and low blueberry (*Vaccinium* spp.); sedges (*Kobresia*, *Carex* spp.), tufted hairgrass (*Deschampsia caespitosa*), alpine timothy (Phleum alpinum), alpine avens (*Geum rossii*), and clover (*Trifolium* spp.).

The alpine tundra zone is located above the subalpine krummholz at elevations over 3,600 m. Tundra vegetation consists of a heterogeneous cover of low sedges, *Juncus* spp., cushion plants, bistort (*Polygonum* spp.), and dwarf shrubs.

Elk migrate through these alpine and subalpine areas in large numbers in the spring and fall, and many spend the majority of the summer on the tundra slopes (Bear, 1989; Braun and others, 1991; Larkins, 1997). A small group of elk also has wintered on the tundra (Bear, 1989; Braun and others, 1991). Diets of elk summering in these areas consisted primarily of graminoids (62–67 percent of total diet), followed by shrubs—particularly willow (11–21 percent), with forbs accounting for the remainder of the diet (9–27 percent, Hobbs and others, 1982).

Methods

In 1971, park biologist David Stevens established twelve 100-ft (30.5-m) transects in alpine tundra (n=8) and subalpine krummholz (n=4) areas of Rocky Mountain National Park in Colorado. Stevens selected representative sites in those vegetation communities and locales receiving the highest elk use (Stevens, 1980, 1992). Transects were chosen nonrandomly and were distributed across the alpine range in easily accessible areas of highest elk densities. Seven of these 12 transects (3 alpine, 4 subalpine) had substantial willow cover. Data on average height and percent cover of shrub species were collected, approximately once every 5 years, using the line intercept method (Canfield, 1941). A modified Daubenmire (1959) technique was used to determine occurrence, and percent cover of herbaceous and small shrub species on transects. These samples were intended to be collected approximately once every five years. This technique involved sampling 21 (20 x 50 cm) plots distributed at 5-ft (1.52-m) intervals along the 100-ft (30.5-m) transect line.

Prior analysis of similar data from low-elevation winter range transects has identified trends in species diversity and shrub cover decline (Zeigenfuss and others, 1999). However, as pointed out in the earlier analysis (Zeigenfuss and others, 1999), these plots were limited in number and not randomly selected, so inference may be limited. Subalpine krummholz transects were sampled in 1971, 1975, 1979, 1984, 1989, and 1996. Tundra transects were sampled in 1971, 1976, 1979, 1985, 1989, and 1996; however, those with willow associations were measured in 1984 instead of 1985, and one tundra turf site was only sampled in 1971, 1976, 1991, and 1996. Orthogonal polynomial contrasts were developed to estimate linear and quadratic polynomials. The data were transformed using contrast coefficients, and the linear and quadratic effects over time were estimated by summing the transformed data for each transect. A one-sample t-test was used to test whether the effects over time were different from zero (no time effect). Analyses were performed using SAS 9.1 (SAS Institute, 2002) statistical software. Percent cover, frequency and height of shrubs for each species, genus groupings (Daubenmire data only), and major vegetation groups (graminoids, forbs, and so forth—Daubenmire data only) were analyzed over time.

I compiled a complete list of species found in the dataset and included current and former scientific names, as well as common names, for each species (see Appendix). Only two species entries out of 5 sampling sessions on 12 transects could not be discerned from the raw data. In many cases, genus and species information was included in one year, but only genus was recorded in subsequent years. When possible to determine the species (for example, only one species of the indicated genus is found in the region/habitat), I added species data to the genus data obtained from the raw data. Because in many years only genus data were available, and therefore, the genus data may fill in missing gaps for a particular species in a given year, I also ran all analyses after grouping all individual entries by genus.

Results

Average cover and height of planeleaf willows *(Salix planifolia)* and short-fruit willow (*S. brachycarpa)* declined over the 25-year period from 1971 to 1996 (figs. 1, 2). *S. planifolia* cover decreased 17.8 percent (P=0.1376), but this decrease was not significant at the 0.05 level. However, the average decline of 25 cm in height over the 25-year period was significant (P=0.0199, fig. 1). *S. brachycarpa* decreased an average of 20.3 percent in cover (P=0.0321) and 24 cm in height (P=0.0258, fig. 2) over the 25 years. Engelmann spruce (*Picea engelmannii)* cover and height increased coincidentally with the decrease of *Salix* on three transects (fig. 3), from no cover in 1971 to an average of 6 percent cover on two subalpine transects and 0.6 percent cover on one tundra transect, but these changes were not different from zero (P=0.13). Percent cover and frequency of grasses and lichens increased over the sampling period (table 1), while overall shrub cover and frequency decreased over this period (P<0.05), as measured using the Daubenmire technique. Percent litter cover and frequency observed responded in a quadratic fashion, increasing initially and then decreasing toward the end of the sampling period (table 1). The frequency of forb and nonvegetative cover types (rock, water, bare ground) were observed to decrease initially and then increase toward the end of the sampling period.

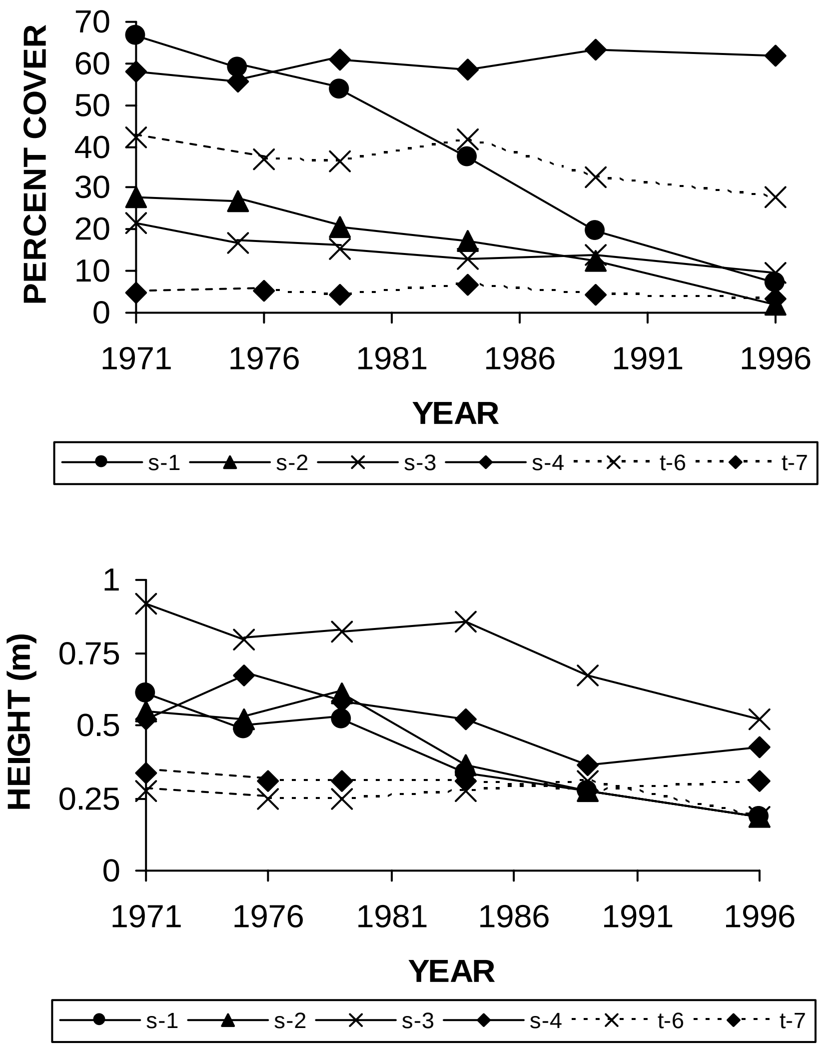
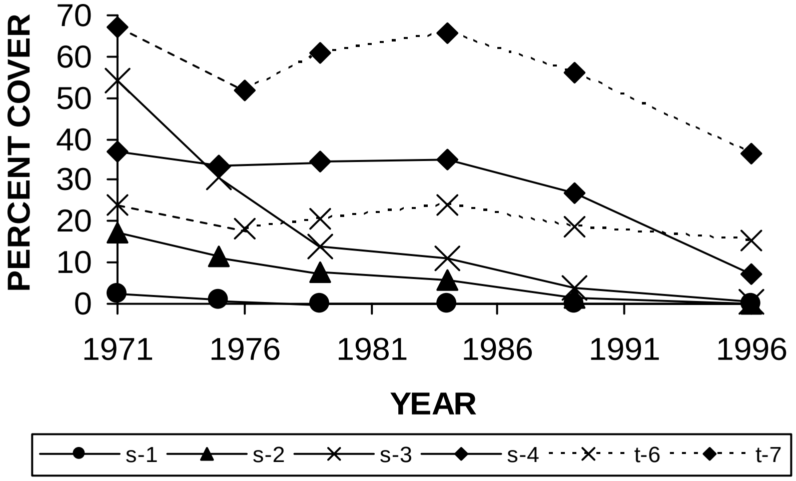


Figure 1. Decreases in percent cover and height (in meters) of *Salix planifolia* on alpine and subalpine transects in Rocky Mountain National Park, Colorado 1971–96. "s" prefix denotes subalpine transects, "t" denotes alpine tundra transects.



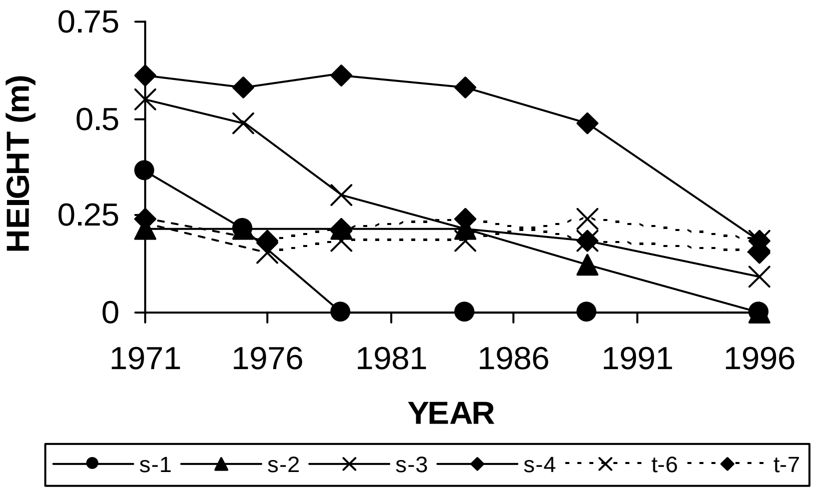


Figure 2. Decreases in percent cover and height (in m) of *Salix brachycarpa* on alpine and subalpine transects in Rocky Mountain National Park, Colorado 1971–96. "s" prefix denotes subalpine transects, "t" denotes alpine tundra transects.

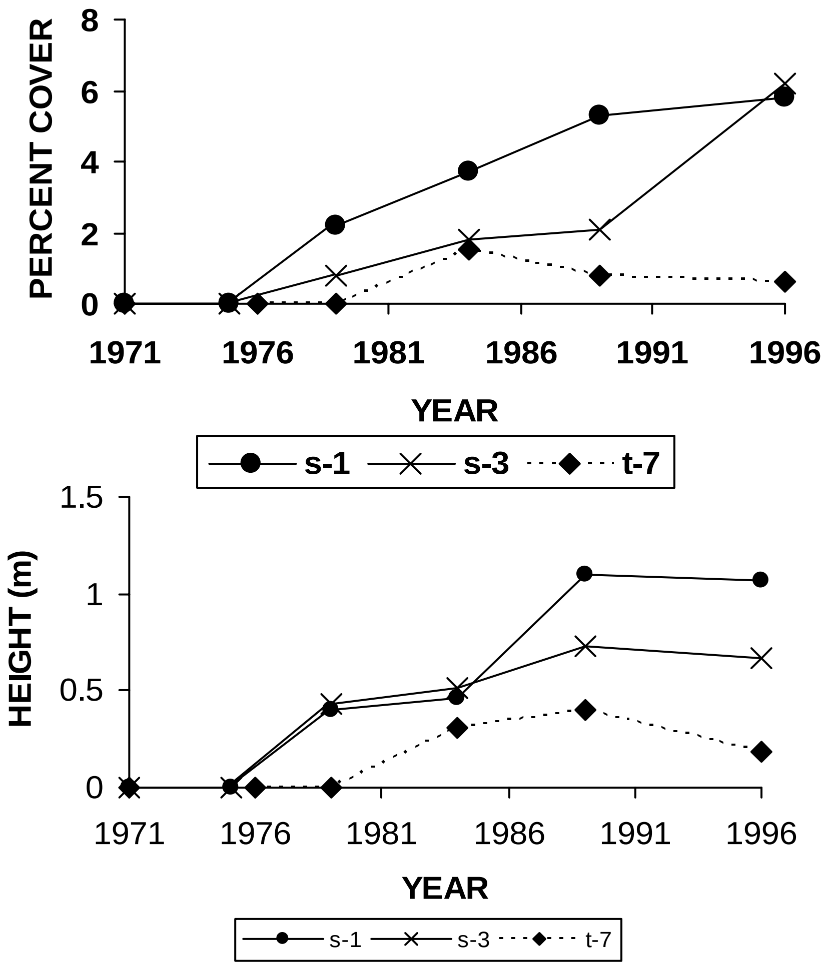


Figure 3. Percent cover and height (in meters) of Engelmann spruce (*Picea engelmannii*) measured on alpine and subalpine transects in Rocky Mountain National Park, Colorado, 1971–96. "s" prefix denotes subalpine transects, "t" denotes alpine tundra transects.

Table 1. Significant changes in vegetation types on alpine and subalpine transects in Rocky Mountain National Park, Colorado, 1971–96. [+ = increasing; – = decreasing; U = quadratic response, decreasing initially then increasing; • = quadratic response, increasing initially then decreasing, < = less than]

Vegetation type	Variable	P-value	T-statistic	Degrees of freedom	Increase/ decrease
Forbs	Frequency	0.0247	2.60	11	U
Graminoids	Cover	0.0133	2.95	11	+
	Frequency	0.0027	3.86	11	+
Lichens	Cover	0.0213	3.09	11	+
	Frequency	0.0216	3.08	11	+
Litter	Cover	0.0074	–3.28	11	•
	Frequency	<0.0001	–8.20	11	•
Shrubs	Cover	0.0073	–3.74	8	–
	Frequency	0.0302	–2.71	8	–
Non-vegetated	Frequency	0.0296	2.50	12	U

Species data indicated changes in cover of many species over the 25-year period (tables 2 and 3). In agreement with observations of earlier reports of Stevens (1980) and Braun and others (1991), I found increases in percent cover of tufted hairgrass (*Deschampsia caespitosa*), but cover of sedges (*Carex elynoides*), bistort (*Polygonum viviparum*), and bluegrasses (*Poa* spp.) also increased. Cover of windflower (*Anemone* spp.) was found to be decreasing. My analysis of the Daubenmire species composition data also found decreasing cover of willow (both *S. brachycarpa* and *S. planifolia*) similar to the line intercept data and as was observed by Stevens (1980) and Braun and others (1991). Several species showed a quadratic response over time. Cover of bedstraw (*Galium* spp.) and violets (*Viola* spp.) increased initially, but then decreased, while alpine sandwort (*Arenaria obtusiloba*), chickweeds (*Cerastium* spp.), and king's crown (*Sedum rosea*) decreased early in the sampling period followed by an increase (tables 2 and 3).

The observed frequency of several species also changed over time (tables 2 and 3). Decreases in frequency of asters (*Aster* spp.) were observed, while frequency of *C. elynoides*, *P. viviparum*, *Trisetum*, *Poa*, fescues (*Festuca* spp.), gentians (*Gentiana* spp.)—particularly alpine gentian (*Gentiana algida*)—, nailworts (*Paronychia* spp.), clovers (*Trifolium* spp.) and Engelmann spruce (*Picea engelmannii*) increased.

Table 2. Significant changes in vegetation genera found on alpine and subalpine transects in Rocky Mountain National Park, Colorado, 1971–96. [+ = increasing; – = decreasing; U = quadratic response, decreasing initially then increasing; • = quadratic response, increasing initially then decreasing, < = less than]

Genus	Variable	P-value	T-statistic	Degrees of freedom	Increase/ decrease
Anemone	Cover	0.0409	–2.50	7	–
Arenaria	Cover	0.0348	3.14	4	U
Aster	Frequency	0.0286	–2.01	7	–
Bare ground	Frequency	0.0222	2.66	11	U
Cerastium	Cover	0.0083	3.37	9	U
	Frequency	0.0004	5.48	9	U
Erigeron	Frequency	0.0451	2.33	9	U
Festuca	Frequency	0.0378	2.36	11	+
Galium	Cover	0.0245	–4.21	3	•
	Frequency	0.0019	–10.39	3	•
Gentiana	Frequency	0.0061	4.13	6	+
Paronychia	Frequency	0.0323	3.22	4	+
Pedicularis	Frequency	0.0055	4.23	6	U
Poa	Cover	0.0531	2.17	11	+
	Frequency	0.0039	3.64	11	+
Polygonum	Frequency	0.0232	2.63	11	+
Potentilla	Frequency	0.0092	3.22	10	U
Salix	Cover	0.0066	–3.81	7	–
	Frequency	0.0246	–2.85	7	U
Sedum	Frequency	0.0042	3.69	10	U
Trisetum	Frequency	0.0479	2.23	11	+
Trifolium	Frequency	0.0145	2.95	10	+
Viola	Cover	0.0492	–2.58	5	U

Table 3. Individual species that showed significant changes in cover and frequency on alpine and subalpine transects in Rocky Mountain National Park, Colorado, 1971–96. [+ = increasing; – = decreasing; U = quadratic response, decreasing initially then increasing; • = quadratic response, increasing initially then decreasing, < = less than]

Species	Variable	P-value	T-statistic	Degrees of Freedom	Increase/decrease
Arenaria obtusiloba	Cover	0.0189	3.81	4	U
Carex elynoides	Cover	0.0149	3.38	6	+
	Frequency	0.0134	3.47	6	+
Carex scopulorum	Frequency	0.0417	–2.49	7	U
Deschampsia caespitosa	Cover	0.0126	3.20	8	+
Gentiana algida	Frequency	0.0325	2.93	5	+
Kobresia myosuroides	Frequency	0.0052	5.55	4	U
Pedicularis bracteosa	Frequency	0.0241	4.24	3	U
Picea engelmannii	Frequency	0.0263	6.05	2	+
Polygonum viviparum	Cover	0.0169	3.12	7	+
	Frequency	0.0061	3.88	7	+
Salix brachycarpa	Cover	0.0281	–3.06	5	–
Salix planifolia	Cover	0.0481	–2.39	7	–
Sedum rosea	Cover	0.0335	2.51	9	U
	Frequency	0.0055	3.63	9	U

The sedge, *Carex scopulorum,* willows (*Salix* spp.), and bedstraw (*Galium* spp.) showed initial increases in frequency followed by declines. Cinquefoils (*Potentilla* spp.), fleabane (*Erigeron* spp.), chickweed (*Cerastium* spp.), stonecrop (*Sedum* spp.)—particularly king's crown (*Sedum rosea*)—, bog sedge (*Kobresia myosuroides*), louseworts (*Pedicularis* spp.)—particularly bracted lousewort (*Pedicularis bracteosa*)—, and bare ground decreased initially and then increased later in the sampling period. In only a few cases were significant changes in cover or frequency found on only subalpine krummholz or alpine tundra transects. Tufted hairgrass (*Deschampsia caespitosa*) cover tended to increase on krummholz transects while remaining rather stable on alpine tundra transects (fig. 4a). Cover of litter increased at a much greater rate on subalpine transects than alpine tundra transects (fig. 4b). A pattern of initial increases in cover, followed by declines was observed for *Festuca* on subalpine krummholz transects and *Anemone* and *Carex* on alpine tundra transects. On alpine tundra transects, cover of chickweed (*Cerastium*) and rock showed decreases in cover, followed by increases over the sampling period that were not observed on the subalpine krummholz transects alone. Moss frequency increased on subalpine krummholz transects over the 25-year period while it decreased, but not significantly on alpine tundra transects over the same period (fig. 5a). Stonecrop frequency decreased in subalpine krummholz transects, but not on alpine tundra transects (fig. 5b). Marsh marigold (*Caltha leptosa*), bedstraw (*Galium*) showed initial increases in frequency, followed by declines on subalpine krummholz transects. The opposite trend (decreasing then increasing frequency) was observed for *Pedicularis* in subalpine krummholz and bare ground, fleabane, stonecrop, and globeflower (*Trollius laxus*) on alpine tundra transects.

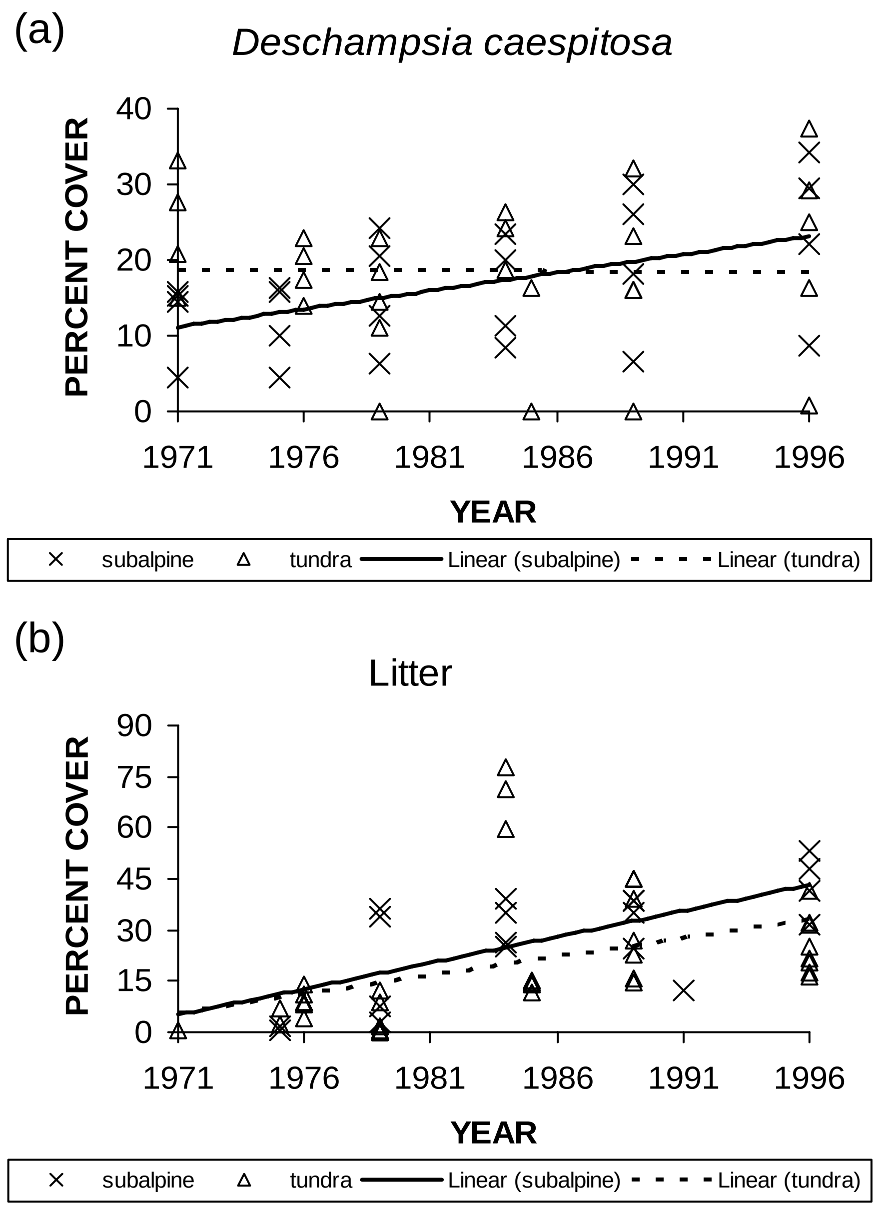


Figure 4. Changes in tufted hairgrass (*Deschampsia caespitosa*) and litter cover in subalpine krummholz and alpine tundra transects in Rocky Mountain National Park, Colorado, 1971–96.

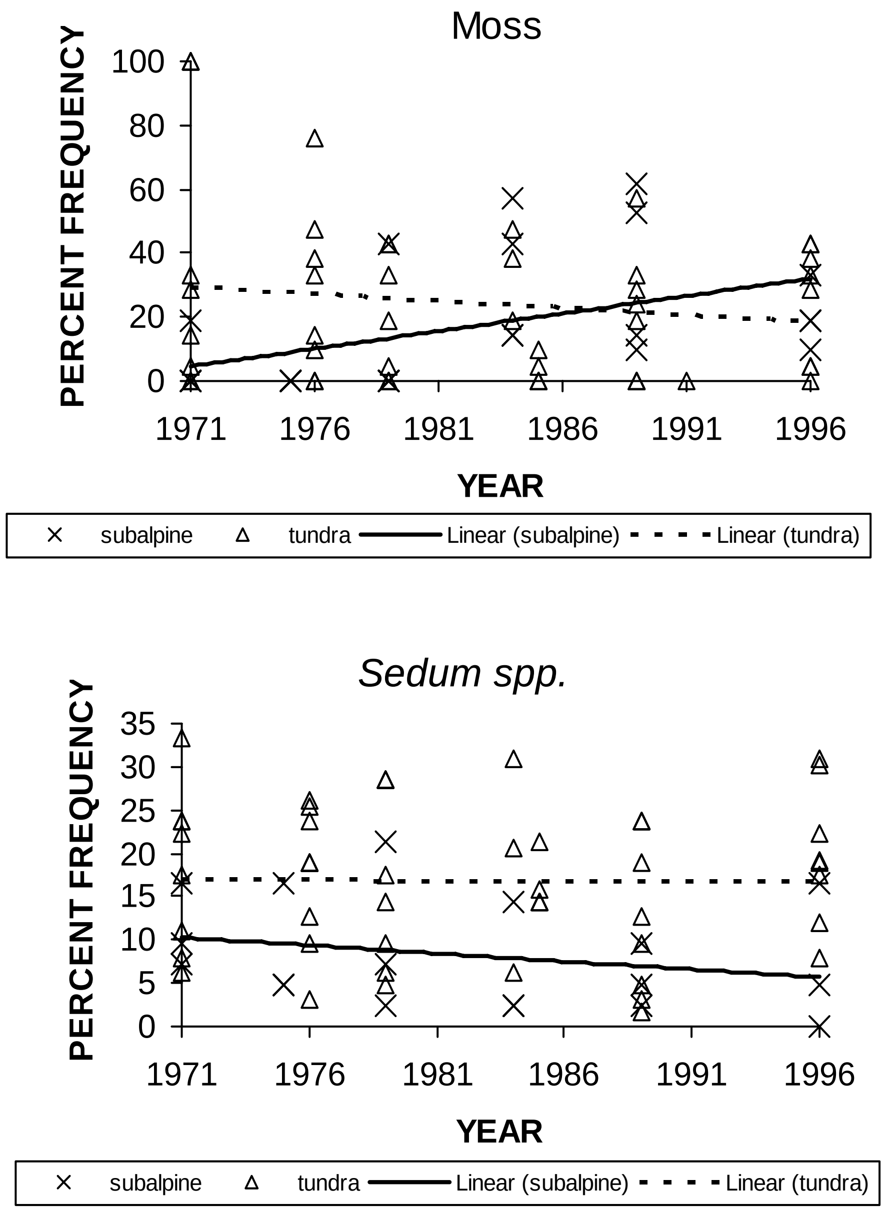


Figure 5. Changes in moss and stonecrop (*Sedum* spp.) frequency in subalpine krummholz and alpine tundra transects in Rocky Mountain National Park, Colorado, 1971–96.

Discussion

Alpine willow cover and height decreased strikingly from 1971 to 1996 in the surveyed subalpine and tundra communities of Rocky Mountain National Park. The collected data did not focus on the dwarf willow species (*S. arctica* [synonymous with *S. anglorum antiplasta*], *S. nivalis* [synonymous with *S. reticulata nivalis*], *S. reticulata*) that might provide more desirable summer forage to white-tailed ptarmigan. May and Braun (1972) found that willow species make up a smaller percentage of summer diets (6 percent) than winter (89 percent) and spring (85 percent) diets for white-tailed ptarmigan throughout Colorado. But observations of foraging behavior of hens and chicks in Rocky Mountain National Park indicated that as much as 38 percent of hen summer diets and 26 percent of chick diets consisted of *S. reticulata* (Allen and Clarke, 2005). So decreases in these species, while important, might not have as significant an effect on white-tailed ptarmigan populations as the non-dwarf species. However, these dwarf species, can still form a portion of winter diets in areas blown free of snow by winter winds.

Analysis of winter ptarmigan habitat in Colorado indicated that ptarmigan use feeding sites with mean snow depths of 72.3 cm in April and mean willow height above snow of 12.4 cm (Giesen and Braun, 1992). This would indicate that as willow heights drop below 85 cm, willow begins to become unavailable as a food for ptarmigan. Currently mean heights of *S. brachycarpa* and *S. planifolia* in the transects are well below 85 cm. However, Giesen and Braun (1992) conducted their studies in an area 80 km south of the Trail Ridge area of RMNP and snow depths may have been considerably deeper in their study area. Studies of winter habitat of white-tailed ptarmigan in Colorado indicate that female ptarmigan winter at or near timberline in dense stands of tall willow, while males winter in krummholz dominated by willows and spruce (Hoffman and Braun, 1977). When snows are deep, these willow species are typically tall enough that the birds access them by walking on top of the snow crust, but at shorter heights the willows may now become completely covered by snow. Therefore, decreasing heights of *S. brachycarpa* and *S. planifolia* should be of concern regarding the future of white-tailed ptarmigan in the park.

Regardless of whether the heights of alpine and subalpine willows are optimal for white-tailed ptarmigan, the fact remains that these data indicate decreasing cover of willows. Based on the information available, I cannot assess whether these transects are representative of all alpine regions in the park. They were selected nonrandomly to reflect areas of heavy elk use and typically tend to be close to the Trail Ridge Road corridor. If all alpine habitats in the park have received similar elk use and have experienced similar weather and human impacts, then alpine krummholz willow can be assumed to be declining throughout the park and, therefore, potentially habitat for white-tailed ptarmigan can be also be assumed to be declining. I recommend a resurvey of the line-intercept work on these transects, if feasible in 2006, to determine whether the downward trend is continuing since the previous measures in 1996. If only the line intercept sampling were done, this work could be conducted in a few days. It would also be useful to have data on percent leader use of shrubs, particularly at the end of summer, to index the degree of ungulate use of shrub species. These data were begun by David Stevens, but only for winter use, and were abandoned because of difficulty in determining use before shrubs had begun a new year's growth.

The decrease in alpine willow cover may or may not be associated with increasing elk population in the park. While many of the roughly 2,000–3,000 elk that winter on the eastern winter range inside and outside the park, spend part or all of the spring and summer on alpine ranges, there are no accurate numbers on summering elk populations. In addition, there is little information on the current size and distribution of the elk population that actually winters on the alpine range. Recent observations of elk in the alpine regions during winter aerial surveys seem to indicate that fewer elk, perhaps only 50–60, are currently wintering on the tundra (Kathryn Schoenecker, U.S. Geological Survey, unpub. Data, 2000–2005). Park management should consider monitoring the summer elk population size and distribution in alpine and subalpine regions of the park and also should attempt to conduct a winter survey whenever feasible. However, winter weather conditions often make it impossible to fly over the alpine regions at an altitude appropriate to observe and count individual elk. It may be possible to conduct ground surveys in both summer and winter, which may not provide an accurate population size but would at least give a minimum number of animals using even the most accessible and visible areas of the park's alpine regions. Alternatively, pellet count transects might be used to get an index of the degree of use these areas are receiving, though pellet counts are considered to be somewhat unreliable and are not good indicators of population size.

Forb and graminoid species of the subalpine and tundra did not seem to show any major declines from 1971 to 1996. There was no significant increase of exotic species in these plots. Alpine tundra environments tend to have the advantage of having low invasibility for most common North American exotics, even in disturbed areas (Weaver and others, 2001). Weaver attributed the poor performance of exotics on disturbed alpine areas to physical limitations that do not allow them to thrive under the short growing season in alpine regions. This fact is particularly important when considering the opportunities for exotic invasion on these grazed sites. There was overall a significant increase in frequency of bare ground, but no coincident increase in bare ground cover was observed. The increases in frequency of observations of bare ground are of interest because they could indicate that while mean bare ground cover does not appear to be increasing, the number of locations where bare ground was found increased over the 25-year period. Increases were concentrated on alpine tundra transects, which are likely the more sensitive of the two community types. If such increases were observed to continue, this could indicate problems from overgrazing and hoof action. While the concerns about invasion of exotic plant species may not be of as great a concern in the alpine as other vegetation zones, there could be loss of species and (or) loss of overall plant biomass and cover with an increase of bare ground, and recovery could take decades in this fragile environment. The absence of a significant decline in bare ground cover may be an artifact of the way the Daubenmire cover classes are set up. Four of the cover classes span a 20–25 percent range of cover. Therefore, it is possible that cover of a species, or in this case, bare ground, could change as much as 25 percent and not be detected when this method is used.

There is not a great wealth of research on the effects of grazing on alpine systems, particularly in the Rocky Mountains. Much of the work that has been conducted focuses on the Alps, Asia, and Australia (where a large component of the overall grazing pressure is from domestic livestock) or on the arctic tundra systems. Galen (1990) investigated the effects of grazing by aphids and mammalian ungulates in limiting distribution of skypilot (*Polemonium viscosum*) in the Rocky Mountains. This study indicated that in this species, grazing was greater on krummholz than tundra populations and that grazing led to complete loss of current year's seed crop and an 80 percent loss of net seed production over 3 years. No significant decrease in this species over the 25-year period was observed from the current data set. Similarly, a study of the subalpine forb, *Ipomopsis aggregata*, indicated that browsing delayed flowering phenology, and while this late flowering led to lowered rates of seed predation, the conclusion was that overall, in areas where the growing season was short, browsing led to reduced plant fitness (Freeman and others, 2003). One might assume a similar effect of high rates of herbivory on many alpine and subalpine forbs.

Del Moral and others (1985) found that simulated grazing of a subalpine *Festuca* species that was dominant in fell fields reduced its yield relative to subordinate species, but a study of green fescue (*Festuca viridula*) in alpine regions of Mount Rainier National Park, indicated that this species is very tolerant of herbivory (Sharrow and Kuntz, 1999). *Festuca* species on the RMNP transects increased in frequency of occurrence from 1971 to 1999, so there does not appear to be an adverse effect of grazing on *Festuca* in the park despite its moderate palatability to grazers. Two graminoid species identified by Hobbs and others (1982) as major elk diet components increased in cover on the transects described in this study, *Deschampsia caespitosa* and a *Carex* species (*C. elynoides*). *Deschampsia* is considered to be of low palatability to grazers, but alpine *Carex* species tend to be moderately palatable. These increases may or may not be due to grazing by elk. Without further information on the levels of elk use at these and other sites in the park, one cannot conclude any reason as to the cause of these increases.

Long-term grazing can alter carbon dioxide and nitrogen dynamics in alpine grasslands (Welker and others, 2004). Grazed areas had higher soil carbon and nitrogen concentrations, but lower plant biomass, lower grass leaf N concentrations, and lower early and late summer N mineralization rates at some sites. This could have implications for plant production and cover under high levels of herbivory in alpine areas, but further data would need to be collected to determine whether herbivory levels in RMNP have been high enough, and for a long enough period of time, to cause these types of changes.

While there is value to continuation of the Daubenmire transects, it appears that the amount of information gained may not warrant the time and expense of monitoring more frequently than every 10 years. Furthermore, if the park wishes to have a more statistically rigorous sampling of alpine regions, more transects should be added in areas that are less accessible from the road to be sure that effects, positive or negative, of human activity on elk distribution and density are accounted for. Such a design should include random placement of transects, or stratification based on observed elk distribution and density, so that a range of elk use levels is included in the sampling.

I also recommend that there be greater consistency in the sampling, with regular sampling intervals, and consistent use of species identifying information. The data presented here suffer from this lack of consistency where one year a plant might be identified to species, another year only to genus, another year only by common name, and so forth. This leads to confusion in data analysis that might be avoided.

My recommendation is that these transects become part of a larger and appropriate inventory and monitoring program. Such a program should have a predetermined level of measurable change that is acceptable to elk and vegetation management goals of the park management staff. Data collection methods should be designed so that (1) the acceptable level of measurable change can be detected, and (2) to the greatest extent possible, existing data previously gathered on the established transects can be compared with data collected in the future under the new inventory and monitoring protocols.

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Appendix

Complete species listing and codes used in electronic data spreadsheets for David Stevens' alpine and subalpine vegetation transects. Collected 1971–96 in Rocky Mountain National Park, Colorado.

Code	Vegtype g=grass, f=forb, s=shrub, x=other	Genus	Species	Common name	Currently accepted name, or older names	Genus grouping for statistical analysis
able	?	*Not determined*	*Not determined*			ablexx
achlan	f	*Achillea*	*lanulosa*	Yarrow		achxxx
achxxx	f	*Achillea*	*spp.*			achxxx
acocol	f	*Aconitum*	*columbianum*	Monkshood		acocol
agoxxx	f	*Agoseris*	*spp.*	False dandelion		agoxxx
agrscr	g	*Agropyron*	*scribneri*	Spreading wheatgrass	*Elymus scribneri*	agrscr
agrxxx	g	*Agrostis*	*spp.*	Bent-grass		agrxxx
aneome	f	*Anemone*	*spp.*	Windflower		aneome
angxxx	f	*Angelica*	*(grayi)*	Angelica		angxxx
aquxxx	f	*Aquilegia*	*spp.*	Columbine		aquxxx
araxxx	f	*Arabis*	*spp.*	Rockcress		araxxx
arefen	f	*Arenaria*	*fendleri*	Fendler's sandwort		arexxx
areobt	f	*Arenaria*	*obtusiloba*	Alpine sandwort	*Minuartia obtusiloba*	arexxx
arexxx	f	*Arenaria*	*spp.*	Sandwort		arexxx
argxxx	f	*?*				argxxx
arncor	f	*Arnica*	*cordifolia*	Heart-leaved arnica		arnxxx
arnxxx	f	*Arnica*	*spp.*	Arnica		arnxxx
artarc	s	*Artemisia*	*arctica*	Arctic sagebrush/ Boreal sagebrush		artarc
artbor	f	*Artemisia*	*borealis*	Field sagewort	*Artemisia campestris borealis*	artxxx
artsco	f	*Artemisia*	*scopulorum*	Alpine sagebrush		artxxx
artxxx	f	*Artemisia*	*spp.*	Sagebrush		artxxx
astxxx	f	*Asteraceae*	*spp.*	Aster		artxxx
betgla	s	*Betula*	*glandulosa*	Bog birch/ Dwarf birch	*Betula nana*	betgla
bg	x	*Bare ground*				bg
bromar	g	*Bromus*	*marginatus*	Mountain brome		broxxx
broxxx	g	*Bromus*	*spp.*	Brome		broxxx
calcan	g	*Calamagrostis*	*canadensis*	Canadian reed-grass		calxxx
callep	f	*Caltha*	*leptosepala*	Marsh marigold		callep
calxxx	g	*Calamagrostis*	*spp.*	Reed-grass		calxxx
camxxx	f	*Campanula*	*spp.*	Harebell		camxxx
camrot	f	*Campanula*	*rotundifolia*	Common harebell		camxxx
caraqu	g	*Carex*	*aquatilis*			carxxx
carely	g	*Carex*	*elynoides*			carxxx
carrup	g	*Carex*	*rupestris*			carxxx
carsco	g	*Carex*	*scopulorum*			carxxx
carxxx	g	*Carex*	*spp.*	Sedge		carxxx
casocc	f	*Castilleja*	*occidentalis*	Western yellow paintbrush		casxxx
casxxx	f	*Castilleja*	*spp.*	Paintbrush		casxxx

cerarv	f	*Cerastium*	*arvense*	Field chickweed		cerxxx
cerbee	f	*Cerastium*	*beeringianum*	Bering chickweed		cerxxx
cerxxx	f	*Cerastium*	*spp.*	Chickweed		cerxxx
colpar	f	*Collinsia*	*parviflora*	Maiden blue-eyed Mary		colpar
cruxxx	f	*Cruciferae*		Unidentified crucifer		unkxxx
danxxx	g	*Danthonia*	*spp.*	Oatgrass		danxxx
delxxx	f	*Delphinium*	*spp.*	Larkspur		delxxx
desalp	g	*Deschampsia*	*alpicola*	Tufted hairgrass	*Deschampsia caespitosa*	descae
descae	g	*Deschampsia*	*caespitosa*	Tufted hairgrass		descae
epixxx	f	*Epilobium*	*spp.*	Willow-herb	*Eritrichium nanum var aretioides*	epixxx
eriare	f	*Eritrichium*	*aretioides*	Arcticalpine forget-me-not		eriare
erigxx	f	*Erigeron*	*spp.*	Fleabane		erigxx
eryniv	f	*Erysimum*	*nivale*	Alpine wallflower	*Erysimum capitatum var. purshii*	eryniv
fesxxx	g	*Festuca*	*spp.*	Fescue		fesxxx
fraxxx	f	*Fragaria*	*spp.*	Strawberry		fraxxx
fungi	x	*Fungi*		Fungi		fungi
galxxx	f	*Galium*	*spp.*	Bedstraw		galxxx
genalg	f	*Gentianodes*	*algida*	"Alpine gentian, whitish gentian"	*Gentiana algida*	genxxx
genama	f	*Gentianella*	*amarella*	"Little gentian, dwarf gentian"		genama
genxxx	f	*Gentian*	*spp.*	Gentian		genxxx
geuros	f	*Geum*	*rossii*	Ross' avens	*Acomastylis rossii (Weber)*	geuxxx
geuxxx	f	*Geum*	*spp.*	Avens		geuxxx
harxxx	f	*Harbouria*	*spp.*	Harbouria		harxxx
helian	f	*Helianthus*	*spp.*	Sunflower		helian
helmor	g	*Helictotrichon*	*mortonianum*	Alpine oat		helmor
hiealp	g	*Hierochloe*	*alpina*	Alpine sweetgrass		hiealp
hymxxx	f	*Hymenoxys*	*spp.*			hymxxx
junxxx	g	*Juncus*	*spp.*	Rush		junxxx
kobmyo	g	*Kobresia*	*myosuroides*	Bog sedge		kobxxx
kobxxx	g	*Kobresia*	*spp.*	Bog sedge		kobxxx
kolcri	g	*Koeleria*	*cristata*	June-grass	*Koeleria macrantha*	kolcri
lichen	l	*Lichen*		Lichen		lichen
lilxxx	f	*Liliaceae*		Lily		lilxxx
litter	r	*Litter*				litter
luzspi	f	*Luzula*	*spicata*	Spiked woodrush		luzspi
lloser	f	*Lloydia*	*serotina*	Common alplily		lloser
mervir	f	*Mertensia*	*viridis*	"Oblongleaf bluebells, green mertensia"	*Mertensia oblongifolia*	merxxx
merxxx	f	*Mertensia*	*spp.*	"Chiming bells, bluebells"		merxxx
moss	m	*Moss*		Moss		moss
orexxx	f	*Oreoxis*	*spp.*	Alpine parsley		orexxx
parpul	f	*Paronychia*	*pulvinata*	Rocky Mountain nailwort		parxxx
parses	f	*Paronychia*	*sessiliflora*	Creeping nailwort		parxxx
parxxx	f	*Paronychia*	*spp.*	Nailwort		parxxx
pedbra	f	*Pedicularis*	*bracteosa*	Bracted lousewort		pedxxx
pedgro	f	*Pedicularis*	*groenlandica*	"Elephantella,		pedxxx

				elephanthead lousewort"		
pedxxx	f	*Pedicularis*	*spp.*	Lousewort		pedxxx
penxxx	f	*Penstemon*	*spp.*	"Penstemon, beard-tongue"		penxxx
phlalp	g	*Phleum*	*alpinum*	Alpine timothy		phlxxx
phlcon	f	*Phlox*	*condensata*	Dwarf phlox		phlxxx
phlxxx	f	*Phlox*	*spp.*	Phlox		phlxxx
phlxxx	g	*Phleum*	*spp.*	Timothy		phlxxx
piceng	s	*Picea*	*engelmannii*	Engelmann spruce		piceng
poaalp	g	*Poa*	*alpina*	Alpine bluegrass		poaxxx
poagla	g	*Poa*	*glauca*	Glaucous bluegrass		poaxxx
poaxxx	g	*Poa*	*spp.*	Bluegrass		poaxxx
polbis	f	*Polygonum*	*bistorta*	Bistort		polxxx
poldel	f	*Polemonium*	*delicatum*	Jacob's ladder	*Polemonium pulcherrimum*	polexx
polexx	f	*Polemonium*	*spp.*	Jacob's ladder		polexx
polvis	f	*Polemonium*	*viscosum*	Sky pilot		polexx
polviv	f	*Polygonum*	*viviparum*	Alpine bistort		polxxx
polxxx	f	*Polygonum*	*spp.*	Bistort		polxxx
potxxx	f	*Potentilla*	*spp.*	Cinquefoil		potxxx
psemon	f	*Pseudocymopterus*	*montanus*	Yellow moutain parsley		psemon
ranxxx	f	*Ranunculus*	*spp.*	Buttercup		ranxxx
ribaur	s	*Ribes*	*aureum*	Golden currant		ribxxx
ribxxx	s	*Ribes*	*spp.*	Currant		ribxxx
rock	x	*Rock*				rock
rumden	f	*Rumex*	*densiflorus*	Dense-flowered dock		rumxxx
rumxxx	f	*Rumex*	*spp.*	Dock		rumxxx
salbra	s	*Salix*	*brachycarpa*	Short-fruit willow		salxxx
salgla	s	*Salix*	*glauca*	Grayleaf willow		salxxx
salniv	s	*Salix*	*nivalis*	Snow willow		salxxx
salpla	s	*Salix*	*planifolia*	Planeleaf willow		salxxx
salxxx	s	*Salix*	*spp.*	Willow		salxxx
saxixx	f	*Saxifraqa*	*spp.*	Saxifrage		saxixx
saxodo	f	*Saxifraqa*	*odontoloma*	Brook saxifrage		saxixx
saxrho	f	*Saxifraqa*	*rhomboidea*	Diamondleaf saxifrage		saxixx
sedlan	f	*Sedum*	*lanceolatum*	Stonecrop		sedxxx
sedros	f	*Sedum*	*rosea*	King's crown	*Rhodiola integrifolia*	sedxxx
sedste	f	*Sedum*	*stenopetalum*	Wormleaf stonecrop		sedxxx
sedxxx	f	*Sedum*	*spp.*	Stonecrop		sedxxx
selsco	cm	*Selaginella*	*scopulorum*	"Lesser spikemoss, Rocky Mountain spikemoss"	*Selaginella densa*	selxxx
selxxx	cm	*Selaginella*	*spp.*	"Little clubmoss, spikemoss"		selxxx
sentri	f	*Senecio*	*triangularis*	Arrowleaf ragwort		senxxx
senwoo	f	*Senecio*	*wootonii*	Wooton's ragwort		senxxx
senxxx	f	*Senecio*	*spp.*	Ragwort		senxxx
sibpro	f	*Sibbaldia*	*procumbens*	Creeping sibbaldia		sibpro
silaca	f	*Silene*	*acaulis*	Moss campion		silxxx
silxxx	f	*Silene*	*spp.*	Campion		silxxx
solxxx	f	*Solidago*	*spp.*	Goldenrod		solxxx

stexxx	f	*Stellaria*	*spp.*	Chickweed		stexxx
sweper	f	*Swertia*	*perennis*	Star gentian		sweper
tarxxx	f	*Taraxacum*	*spp.*	Dandelion		tarxxx
thaalp	f	*Thalictrum*	*alpinum*	Alpine meadow-rue		thaxxx
thaxxx	f	*Thalictrum*	*spp.*	Meadow-rue		thaxxx
thlalp	f	*Thlaspi*	*alpestre*	Alpine pennycress	*Thlaspi montanum*	thlx
tridas	f	*Trifolium*	*dasyphyllum*	Alpine clover		trixxx
trinan	f	*Trifolium*	*nanum*	Dwarf clover		trixxx
tripar	f	*Trifolium*	*parryi*	Parry's clover		trixxx
trispi	g	*Trisetum*	*spicatum*	Spike trisetum		trisxx
trisxx	g	*Trisetum*	*spp.*	Trisetum		trisxx
trixxx	f	*Trifolium*	*spp.*	Clover		trixxx
trolax	f	*Trollius*	*laxus*	Globeflower	*Trollius albiflorus (older name)*	trolax
unkxxx	f	*Forb*		Unknown forb		unkxxx
unkxxx	g	*Grass*		Unknown grass		unkxxx
vacsco	s	*Vaccinium*	*scoparium*	Broom huckleberry		vacxxx
vacxxx	s	*Vaccinium*	*spp.*	Huckleberry		vacxxx
verbxx	f	*Verbena*	*spp.*	Verbena		verbxx
verxxx	f	*Veronica*	*spp.*	Veronica		verxxx
viobel	f	*Viola*	*bellidifolia*	Mountain blue violet	*Viola adunca*	vioxxx
vioxxx	f	*Viola*	*spp.*	Violet		vioxxx
water	x	*Water*				water