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Five-Year Effects of Introduced Mountain Goats and Recreation on Plant Communities and Species of Conservation Concern in an Alpine Sky Island

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Abstract.—Alpine ecosystems in the arid southwestern United States are vulnerable to climate change. Many of these ecosystems are experiencing increased recreational use and introductions of nonindigenous ungulates. In the La Sal Mountains of southeastern Utah, alpine plant communities support an endemic plant species, *Erigeron mancus*, 11 plant and two animal species of conservation concern, and a United States Department of Agriculture (USDA) Forest Service Research Natural Area. Nonindigenous mountain goats (*Oreamnos americanus*) were introduced by the Utah Division of Wildlife Resources (UDWR) in 2013 and 2014, and recreational use has increased in the intervening period. To evaluate potential effects of mountain goat and recreational use, vegetation monitoring was initiated by the USDA Forest Service in 2016. We used 5 y monitoring data (2016–2020) and generalized linear mixed models to analyze the separate and interacting effects of year, recreational use, and mountain goat use on: (1) populations of plant species of conservation concern; (2) vascular and nonvascular plant cover; and (3) ground cover. Our analyses revealed decreases in proportional frequency of *E. mancus* at the end of the monitoring. Proportional cover of dominant plant growth forms, especially forbs, declined, while proportional cover of litter and ineffective ground cover (bare soil and pavement) increased. Recreational or goat use were a factor in several of the observed changes, although weather and climate likely also influenced the results. Management complexity arises because of the different missions of USDA Forest Service and UDWR, but adjustments in mountain goat numbers and recreational use may be needed to maintain ecologically resilient ecosystems. Continued monitoring can provide the basis for adaptive management.

Introduction

Alpine ecosystems are biologically diverse and support large numbers of endemic species (Körner, 2004), but are vulnerable to climate change and increasingly threatened by human activities. High-elevation ecosystems are characterized by harsh environmental conditions that have repeatedly triggered speciation and the evolution of novel traits to cope with the strong winds, extended periods at low temperatures, ultraviolet radiation, and short growing seasons (Chapin and Körner, 1995; Nagy and Grabherr, 2009). High mountains generally have been less impacted than lower elevation areas by anthropogenic activities and are considered the “last refugia” for a large number of species, many of which are endemic to a single mountain range (Huxley and Spasojevic, 2021). Alpine ecosystems are among the

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most vulnerable to ongoing changes in climate (Intergovernmental Panel on Climate Change (IPCC), 2014; Pepin *et al.,* 2015) and in the western U.S. are experiencing increased stress due to accelerating recreational use (Hammitt *et al.*, 2015; Gutzwiller *et al.*, 2017) and intentionally introduced ungulate species (Long, 2003; Spear and Chown, 2007). The cumulative effects of these global change processes in alpine ecosystems have the potential to reduce ecological resilience and require long-term monitoring to develop effective management strategies.

Climate change has wide-ranging impacts on alpine ecosystems, and many of these are already documented globally (Huss *et al.*, 2017; Guisan *et al.*, 2019; Hock *et al.*, 2019; Verall and Pickering, 2020). Mountain ecosystems are currently warming faster than the global average, which is a trend that is expected to accelerate (Pepin *et al.*, 2015). Impacts of climate warming vary globally, but include changes in albedo, cloud cover, and water vapor, leading to decreases in winter and spring snowpack, increases in minimum temperatures, and longer growing seasons (IPCC, 2014; Pepin *et al.*, 2015). These climate changes may further limit the suitable habitat available for geographically-restricted alpine endemics and cryophilic species (Walther *et al.*, 2005; Dirnböck *et al.*, 2011) and necessarily are an underlying consideration in assessing anthropogenic impacts on alpine ecosystems and developing management strategies.

The effects of recreation activities on mountain ecosystems are well documented. Activities, such as hiking, can result in both acute and chronic trampling of various types of vegetation with effects ranging from short-term loss of plant cover to long-term changes in species composition (Kuss, 1983; Cole, 2004; Hammitt *et al.*, 2015). These activities can also increase soil erosion and affect other ecosystem properties via direct effects of air and water pollution and associated feedbacks (Cole, 2004; Hammitt *et al.*, 2015). Recreationists affect wildlife by close and repeated approaches, chasing, or other circumstances that alert or alarm individuals (Gutzwiller *et al.*, 2017). These activities may displace wildlife from preferred environments, increase avoidance behavior and hence energy expenditure, promote detection by predators, and disrupt parental care resulting in reductions in reproduction rates and population levels (Gutzwiller *et al.*, 2017). Understanding relationships between recreation attributes (*e.g.*, timing, intensity, duration, and location) and consequent ecosystem responses is essential for developing sustainable management solutions.

Ungulate species have been introduced to alpine ecosystems around the globe, primarily for sport hunting or for food (Long, 2003). In the western U.S., mountain goats (*Oreamnos americanus*) have been introduced into mountain ecosystems by state wildlife agencies primarily to provide opportunities for sport hunting and wildlife viewing [*e.g.*, Utah Division of Wildlife Resources (UDWR), 2021]. When ungulates are introduced into areas where they did not occur previously (*i.e.,* they are nonindigenous) or their numbers exceed the carrying capacity, they can negatively affect the ecosystem's biological diversity and ecological resilience (Spear and Chown, 2009). The potentially negative impacts of nonindigenous ungulates such as mountain goats and their social and economic importance can lead to competing interests and conflicts regarding their management (Anunson and Anunson, 1993; Scheffer, 1993; Lyman, 1994; Hutchins, 1995).

Mountain goats have been introduced from their native range in the northern Rocky Mountains into alpine ecosystems in Colorado, such as Mt. Evans (Weber, 2010), in Washington, such as Olympic National Park (Houston *et al.*, 1994), and in Yellowstone National Park in Wyoming (Festa-Bianchet and Côté, 2004), with similar effects on plant species and communities. Recent research in the Rocky Mountains and Cascades indicates mountain goats largely select rugged and steep areas at high elevations characterized by high solar exposure and low vegetation cover; they select lower elevations and warmer aspects in winter (Lowrey, 2017; White, 2017). Mountain goats affect alpine plant species and communities via trampling, grazing, and wallowing (Houston *et al.*, 1994). On Mt. Evans, effects included reduction in the unique moss flora and alpine plant species (Weber, 2010). In Olympic National Park, total plant cover was lower in high goat density areas and goats caused increased disturbance in a wide variety of plant communities, irrespective of species composition (Houston *et al.*, 1994). In Yellowstone National Park, ridgetop vegetation cover was lower and barren areas along alpine ridges were more prevalent in areas with relatively high goat use (Aho and Weaver, 2003). It was estimated that it would take between 10–20 y for plant communities to recover in the absence of goats in Olympic National Park (Schreiner and Woodward, 1994), and in drier alpine ecosystems recovery times may be even longer.

This study evaluated the 5 y effects of introduced, nonindigenous mountain goats and recreational use on an alpine sky island of the La Sal Mountains in southeastern Utah. The La Sal Mountains are an insular, laccolithic mountain range on the Colorado Plateau with peaks over 3660 m (Blakey and Ranney, 2008). The area supports an endemic plant species, *Erigeron mancus* (Fowler *et al.*, 2010, 2018), and 11 plant and two animal species of conservation concern identified in the Manti-La Sal National Forest Plan revision process [United States Deartment of Agriculture (USDA) Forest Service, 2017]. To protect ecosystem structure and function in representative alpine and subalpine habitats of the La Sal Mountains, the USDA Forest Service established the Mt. Peale Research Natural Area (RNA) in 1986 (USDA Forest Service, 1986).

Mountain goats were introduced to the La Sal Mountains in 2013 and 2014 by the UDWR. The mountain goats inhabit the alpine areas of the La Sal Mountains including the Mt. Peale RNA. The UDWR estimated the mountain goat population at 105 in 2019 (UDWR, 2019) and 85 to 100 goats in 2021 (D. Mitchell, pers. comm.). The Manti-La Sal National Forest Moab District recreation manager determined that areas of high recreational use occur in alpine areas inhabited by mountain goats along and adjacent to designated trails used to access peaks and traverse mountain ridges above 3048 m (USDA Forest Service, 2016).

Stewardship of these ecosystems requires collaboration between the federal agency responsible for managing the "land" or ecosystems, typically the USDA Forest Service or National Park Service in the case of mountain goats, and the state agency responsible for managing the wildlife. Limited information on alpine plant communities and status and trends of plant species of conservation concern, coupled with the potential for mountain goats and recreational use to impact these plant communities and species, indicated a need to monitor areas where goats were introduced. To evaluate potential effects of mountain goat introduction and recreational use in the La Sal Mountains, an Alpine Vegetation Monitoring Plan was developed and implemented by the USDA Forest Service and UDWR (2017).

We used 5 y monitoring data from the La Sal Mountains to evaluate the separate and interacting effects of year, recreational use, and mountain goat use over time on: (1) populations of plant species of conservation concern; (2) cover of vascular and nonvascular plants; and (3) ground cover. We discuss changes over the 5 y period (2016 through 2020), the likely effects of climate/weather, recreational use, and mountain goat use, and the management challenges.

METHODS

Study area.—The study area was located across the La Sal Mountains on the Manti-La Sal National Forest and included the Mt. Peale Research Natural Area (RNA). In general terms,

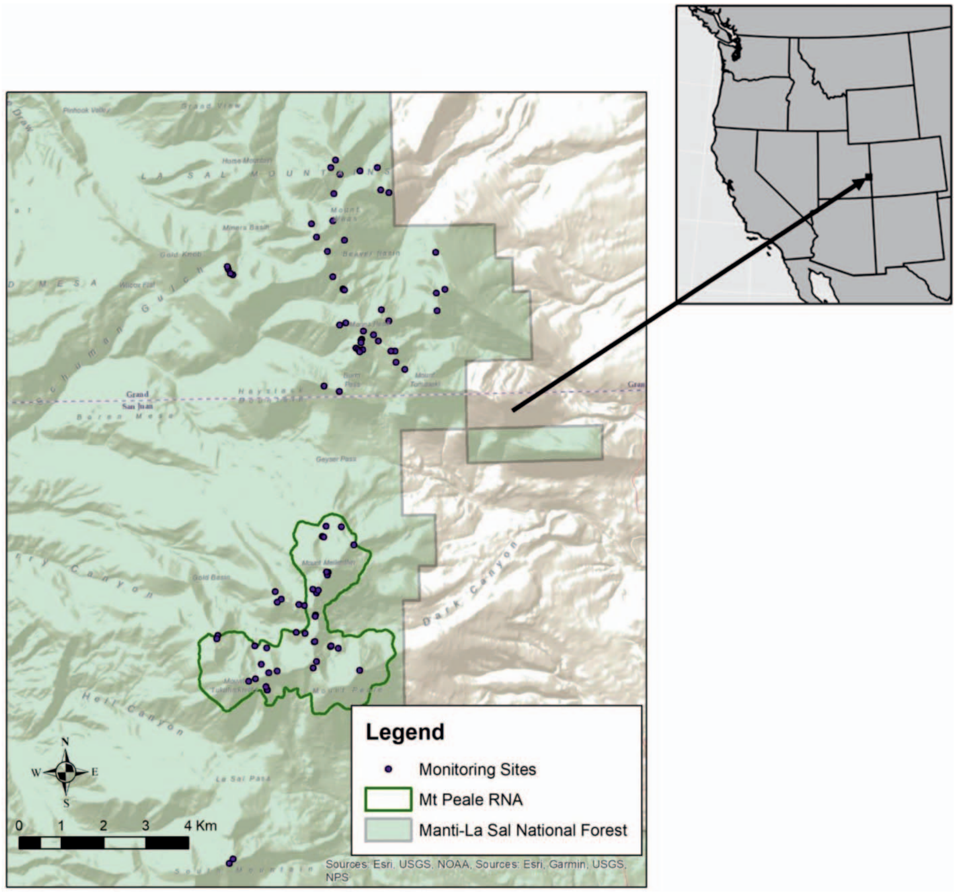

FIG. 1.—Locations of the La Sal Mountain alpine vegetation monitoring sites and the Mt. Peale RNA which are in the southeastern part of the state of Utah in the western United States

the area could be described as Rocky Mountain Alpine Fell-field as identified in the International Terrestrial Ecological System classification (NatureServe, 2022). The approximate coordinates of the area were 38°30′00″N, 109°14′30″W and the elevation ranged from 3295 to 3842 m. Mean annual precipitation during the 5 y study was 787 mm and ranged from 472 mm in 2018 to 1057 mm in 2019. Mean annual temperature was 5.1 C and ranged from 6.3 C in 2018 to 4.1 C in 2019. Data were obtained from a La Sal Mountain Snowpack Telemetry Network (SNOTEL) site (no. 572), which is at an elevation of 2919 m [USDA Natural Resources Conservation Service (NRCS), 2021].

Monitoring sites were located in areas of habitat for three plant species of conservation concern, *Erigeron mancus*, *Androsace chamaejasme* ssp. *carinata* and *Senecio fremontii* var. *inexpectatus*, for the Manti-La Sal National Forest (USDA Forest Service, 2017) and Utah Native Plant Society (Alexander, 2016; Fig. 1). *Androsace chamaejasme* ssp. *carinata* and *Androsace chamaejasme* ssp. *lehmanniana* are listed as separate subspecies in USDA Plants (2021), but as synonyms in the Integrated Taxonomic Information System (ITIS, 2021) and

Flora of North America (FNA, 2021). *Erigeron mancus* and *S. fremontii* var. i*nexpectatus* are listed as critically imperiled (G1 and T1, respectively) under the NatureServe Conservation Status guidelines (NatureServe, 2021). *Androsace chamaejasme ssp. carinata* does not have a NatureServe ranking, but is considered a USDA Forest Service Region 4 species of conservation concern in Utah, because it occurs only in alpine habitats of the La Sal Mountains (USDA Forest Service, 2016b). *Erigeron mancus* and *Androsace chamaejasme* ssp. *carinata* often occur together in patchy, alpine cushion plant habitat, whereas *Senecio fremontii* var. *inexpectatus* occurs in association with persistent snowbanks and talus/cliff habitats. Species that occur with high frequency in the area include forbs: *Achillea millefolium, Castilleja sulfurea, Cerastium arvense, Cymopterus lemmonii, Eremagone fendleri, Geum rossii, Solidago multiradiata,* and *Trifolium dasyphyllum*; and graminoids: *Carex elynoides, Festuca brachyphylla,* and *Poa abbreviata* (Fowler and Smith, 2010).

Data collection.—To select monitoring sites, polygons with populations of plant species of conservation concern were delineated in a Geographic Information System (GIS) based on Manti-La Sal Forest data and vegetation layers (USDA Forest Service, 2015), Utah Natural Heritage database points, habitat models, and ongoing surveys of habitat of plants of conservation concern. For efficiency of sampling, sites were selected within these polygons that had a minimum size of 45 m^2, slope less than 30% at *E. mancus* and *A. chamaejasme* ssp. *carinata* sites, and slope less than 45% at *S. fremontii* var. *inexpectatus* sites. A total of 81 monitoring sites were established and permanently marked with conduit, GPSed, and photographed (Fig. 1). This included all accessible *E. mancus* occupied habitat within the area that met the size and slope criteria.

To evaluate effects of recreational use, the 81 monitoring sites were designated as high versus low summer recreational use areas based on maps developed by the Moab District recreation manager (USDA Forest Service, 2016a). Mapped high recreational use areas included areas within 15 m of designated trails and routes above 3050 m that are commonly used to hike along ridges and access peaks. Low use areas were all other areas. An average of 18 high recreational use and 56 low recreational use sites were sampled each year.

Monitoring was initiated in 2016 using standard protocols for evaluating trends in plant species and plant communities over time (Bonham, 2013). At each monitoring site, data were collected on the presence or absence of the plant species of conservation concern, and on the cover of vascular plants, nonvascular plants, litter, bare soil, pavement (rock fragments 2 to 19 mm in diameter on soil surface), and rock (>19 mm in diameter). Vascular plant cover was collected for the two dominant growth forms–graminoids (grasses and carices) and forbs.

A frequency protocol was used for the plant species of conservation concern in which four 1-m^2 plots were located at each monitoring site (Bonham, 2013). Presence or absence data (P/A) from 100, 10 cm $\times$ 10 cm grid cells within each 1 m^2 plot were obtained for each species by counting the number of grid cells in which it occurred. The number of P/A observations equaled 100 per plot and 400 per site. Sampling constraints (*e.g.,* persistent snow) limited the number of plots that were sampled each year; the number of sites surveyed was 70 in 2016, 70 in 2017, 78 in 2018, 72 in 2019, and 80 in 2020.

Cover of graminoids, forbs, nonvascular plants, litter, bare soil, pavement, and rock were recorded from the same 1 m^2 grid used for monitoring the plant species by vertically inserting a pin at the upper left corner of each 10 cm square and recording what the pin touched at the ground surface (Elzinga *et al.,* 1998). The total number of surface hits equaled 100 points per plot and 400 points per site.

Cameras were installed at randomly selected monitoring sites to monitor both ungulate and human recreational presence across the area. Twelve cameras were used to monitor the selected sites during the summer (May 1–Oct. 31) and eight in the winter (Nov. 1–Apr. 30). In 2019 through 2020, 95% of the ungulates recorded at camera monitoring sites were mountain goats ($n = 3521$ occurrences; USDA Forest Service, 2021). During the summer of 2020, the cameras recorded 925 recreationists (USDA Forest Service, 2021).

Ungulate use was evaluated from pellet group transects (Neff, 1968). At each monitoring site a pellet group transect was placed in the same area and within the same or similar plant community type as the frequency and cover transect. A random starting point was selected near the frequency and cover transect. Circular plots 9.3 m^2 in area were spaced approximately 6 m apart along the transect. The number of plots was 25 or 50, depending on the size of the focal plant community. Some studies have shown that pellet groups can persist on the landscape for multiple years (Neff, 1968), but in harsh alpine environments greater precipitation and exposure (Harestad and Bunnell, 1987), vegetated substrates, freeze-thaw cycles (Lehmkuhl *et al.*, 1994) and steep slopes (Wallmo *et al.*, 1962) decrease pellet group persistence. We attempted to count only recent ungulate pellet groups (estimated to be less than 1 y old by color, cracking, hardness, and amount of scattering). The pellet group counts were converted to days used per ha (Neff, 1968; USDA Forest Service and UDWR, 2017). Because the data from the camera monitoring sites indicated almost all use was by mountain goats, the pellet group counts were converted to goat days use per ha (goat days use).

Data analyses.—We used generalized linear mixed models (GLMMs) to evaluate the effects of year (2016–2020), recreational use (high or low), goat days use, and their interactions on plant species of conservation concern, vascular and nonvascular plants, and ground cover variables. Year and recreational use were categorical effects, and goat days use was a continuous variable. The response variables included proportional frequency for the plant species of conservation concern, and proportional cover for graminoids, forbs, nonvascular plants, litter, rock, bare soil, and pavement, as well as ineffective ground cover (the combination of bare soil and pavement; US Forest Service, 2005c). The only exception to the model specification was for *S. fremontii var. inexpectatus* in which the year by recreation use interaction term was excluded because only two plots existed in high recreational use areas. All of the models incorporated a beta distribution (Bonham, 2013) with repeated measures and an unstructured variance-covariance dependence relationship. The beta distribution describes continuous responses on the open interval of $0 < x < 1$, and accounts for spatial aggregation (Daamgard and Irvine, 2019). Because our data contained some instances of exactly 0 or 1, we used the scaling algorithm described in Smithson and Verkuilen (2006) to allow all observations to be included in our models. The unstructured variance-covariance relationship accounted for correlation among observations due to proximity or time in the standard error estimates, alleviating any influence of dependence.

The designations for recreational use were consistent over time and the same plots were used for each sample year in all analyses, although plot numbers differed due to sampling constraints. The distributions of the pellet counts for the monitoring sites over the 5 y are in Appendix 1. For the plant species of conservation concern, which occurred in unique habitats, only those plots in which the specific species occurred were used in the analyses.

We used the main effect of year to evaluate annual differences in the plant species of conservation concern, vascular and nonvascular plants and ground cover variables over the 5 y monitoring period. For this comparison, the year effect for each response was estimated at fixed levels of mean goat days use and mean or neutral recreational use that were considered

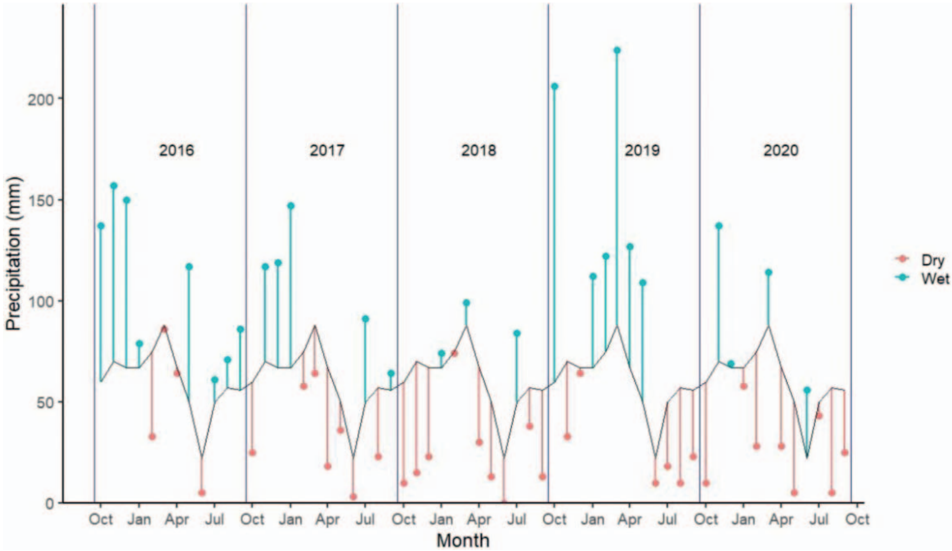

FIG. 2.—Mean monthly precipitation and its deviation from the 30-y norm for the 5-y monitoring period for the La Sal Mountains. Data are derived from a La Sal Mountain SNOTEL site (no. 572) which is at an elevation of 2919 m (NRCS, 2021)

typical of the study area. In instances when interactions existed between year and goat days use or year and recreational use, the year effect was more complex. In these cases, the dependence of year relevant to the interaction included the full ranges of the covariates involved in the interaction. Model estimates were expressed as proportional frequency or proportional cover and reported as least squares (LS) means. We used $\alpha = 0.05$ to indicate significant main and interacting effects. To evaluate significant differences among model estimates, we used pairwise comparisons adjusted using the Tukey-Kramer method at $\alpha = 0.05$. GLMM analyses were performed using Base SAS software, version 9.4 and SAS/STAT software version 15.2, copyright © 2020 SAS Institute Inc.

Ideally, the effect of yearly and growing season precipitation would be included in the models as a covariate. However, because precipitation data were only available for the entire monitoring area and not individual monitoring sites, it was not possible to include it as a covariate in the models. To illustrate trends during the monitoring period, information on mean monthly precipitation and its deviation from the 30 y norm for 1991–2020 were derived from a La Sal Mountain SNOTEL site (no. 572), which is at an elevation of 2919 m (NRCS, 2021). Spearman's rank correlation coefficients were calculated to evaluate the relationship of growing season precipitation with the proportional frequency of the target plant species and proportional cover of the graminoids and forbs.

RESULTS

PRECIPITATION DURING THE MONITORING PERIOD

Over the 5 y monitoring period, monthly precipitation was relatively low in 2018 and 2020 compared to the 30 y means (Fig. 2). Monthly precipitation was high in 2016 and 2019, and intermediate in 2017 (Fig. 2). Growing season precipitation was positively correlated with

TABLE 1.—Results of the mixed model analyses for (A) plant species of conservation concern, (B) graminoid, forb, nonvascular plant, and litter cover, and (C) bare soil, pavement, rock, and ineffective ground cover. DF = degrees of freedom. Values in bold are significant at $\alpha = 0.05$

(A)

Effect	DF	Erigeron F value	Erigeron P value	Androsace F value	Androsace P value	Senecio F value	Senecio P value
Yr	4	10.01	**<.0001**	2.53	0.0556	10.94	**0.0017**
Rec	1	0.74	0.3937	1.58	0.2161	2.52	0.1470
Y × Rec	4	3.60	**0.0101**	0.82	0.5212		
Goat Days Use	1	0.09	0.7682	1.72	0.1968	1.74	0.2200
Y × Goat Days Use	4	3.33	**0.0148**	0.21	0.9315	9.90	**0.0024**
Rec × Goat Days Use	1	0.19	0.6657	0.91	0.3466	9.07	**0.0147**

(B)

Effect	DF	Graminoid F value	Graminoid P value	Forb F value	Forb P value	Nonvascular plant F value	Nonvascular plant P value	Litter F value	Litter P value
Yr	4	6.53	**0.0001**	42.81	**<.0001**	3.87	**0.0062**	15.81	**<.0001**
Rec	1	0.91	0.3440	7.97	**0.0059**	7.42	**0.0079**	0.09	0.7608
Y × Rec	4	1.50	0.2094	4.97	**0.0012**	1.67	0.1635	4.25	**0.0035**
Goat Days Use	1	0.07	0.7959	4.19	**0.0437**	0.93	0.3373	0.94	0.3345
Y × Goat Days Use	4	1.29	0.2822	2.01	0.1003	0.51	0.7265	1.68	0.1613
Rec × Goat Days Use	1	6.48	**0.0128**	8.43	**0.0047**	0.01	0.9391	0.09	0.7657

(C)

Effect	DF	Bare soil F value	Bare soil P value	Pavement F value	Pavement P value	Rock F value	Rock P value	Ineffective cover F value	Ineffective cover P value
Yr	4	4.46	**0.0026**	11.97	**<.0001**	6.63	**0.0001**	7.03	**<.0001**
Rec	1	0.45	0.5023	0.14	0.7051	0.31	0.5820	0.00	0.9616
Y × Rec	4	4.43	**0.0027**	1.22	0.3099	0.90	0.4653	4.00	**0.0051**
Goat Days Use	1	0.09	0.7587	3.47	0.0660	0.02	0.8913	6.33	**0.0138**
Y × Goat Days Use	4	0.63	0.6392	1.83	0.1308	3.23	**0.0163**	1.82	0.1332
Rec × Goat Days Use	1	0.00	0.9942	1.18	0.2804	1.07	0.3039	2.63	0.1086

the proportional frequency of *Senecio fremontii* var. *inexpectatus* ($r = 0.43$, $P = 0.002$), proportional cover of forbs ($r = 0.31$, $P < 0.001$) and proportional cover of graminoids ($r = 0.12$, $P = 0.019$) as indicated by Spearman's rank correlation co-efficients.

RESPONSE OF PLANT SPECIES OF CONSERVATION CONCERN

Erigeron mancus was sampled in higher numbers of plots than the other plant species of conservation concern ($n = 56$ to 65). There was an overall effect of year (Table 1A) in that mean proportional frequency in those plots where it occurred was lower in 2020 (22.9%) than in 2016 (30.5%), 2017 (32.4%), 2018 (31.4%) and 2019 (30.9%) (Fig. 3). An interaction existed between year and recreational use (Table 1A) in that high recreational use plots had lower proportional frequency in 2020 than either low or high recreational use

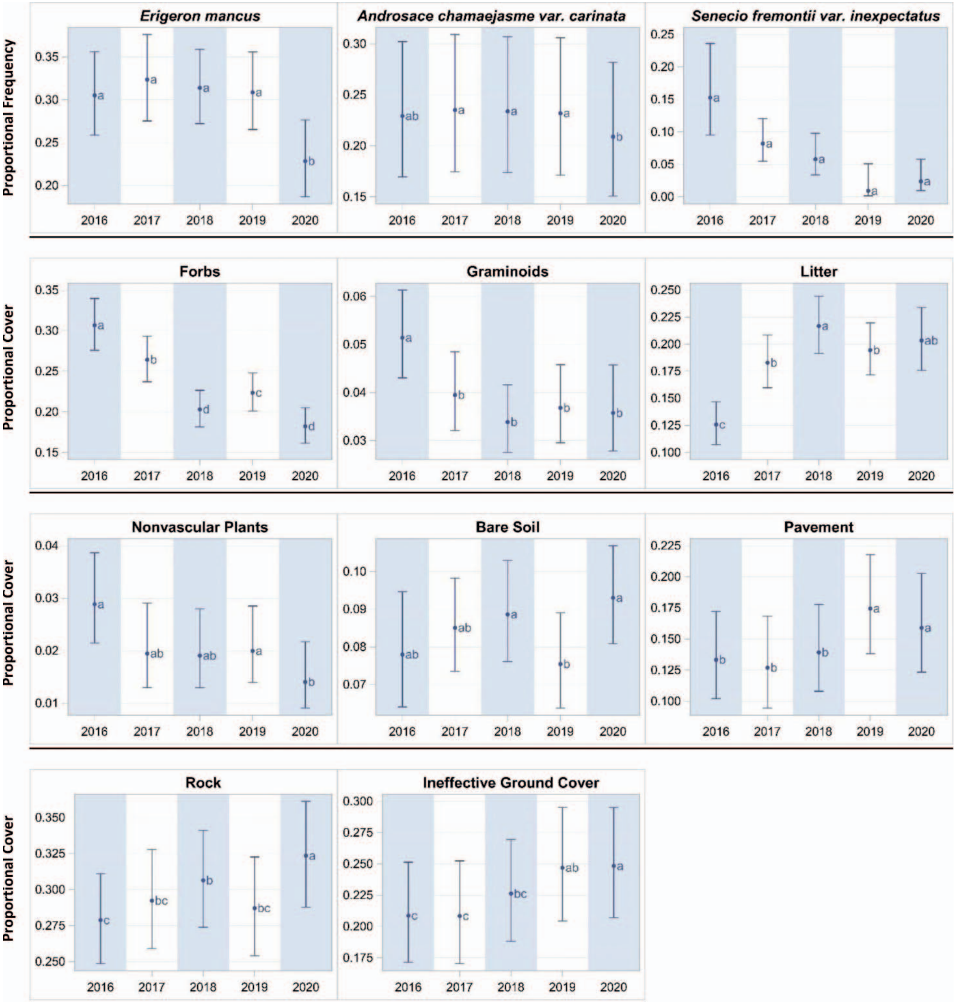

FIG. 3.—The estimated proportional frequency of the plant species of conservation concern and proportional cover of the plant functional groups and ground cover for each of the five study years. Values are LS means and 95% confidence intervals. Proportions are estimated at mean goat days use per ha and mean or neutral recreation use and do not represent interactions between year and goat days use or year and recreational use. Differences in lowercase letters indicate significant differences ($\alpha = 0.05$) among years. The response scales vary to better illustrate the observed range of the data

plots in most prior years (Fig. 4). In addition, an interaction existed between year and goat days use (Table 1A). Proportional frequency of *E. mancus* was negatively related to goat days use in 2018, 2019, and 2020 (Fig. 5), but the model estimates were not significant.

Androsace chamaejasme ssp. *carinata* was present in the second highest number of plots ($n =$ 32 to 39). There was a trend towards a difference among years (Table 1A) in that mean proportional frequency in those plots where this species occurred was higher in 2017

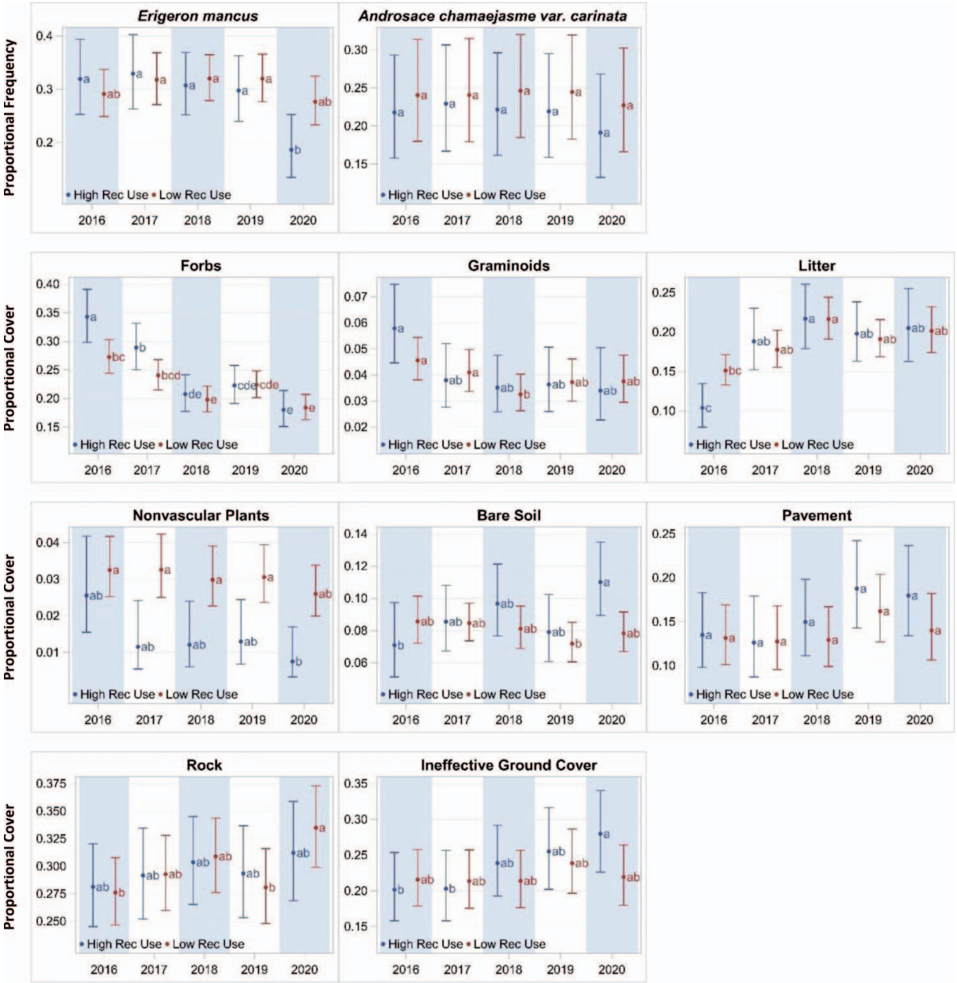

FIG. 4.—The estimated proportional frequency of the plant species of conservation concern and proportional cover of the plant functional groups and ground cover for each of the five study years plotted in relation to high and low recreational use. Values are LS means and 95% confidence intervals. Differences in lower-case letters indicate significant differences ($\alpha = 0.05$) among years. The response scales vary to better illustrate the observed range of the data

(23.5%), 2018 (23.4%) and 2019 (23.2%) than in 2020 (20.9%) (Fig. 3). However, mean proportional frequency in 2016 (22.9%) did not differ from the other years. There were no differences attributable to recreational use or goat days use.

Senecio fremontii var. *inexpectatus* was present in low numbers of plots ($n = 7$ to 12) because it grows on steep loose slopes, rock cliffs/outcrops, or in association with persistent snowbanks, and is difficult to sample. There was an overall effect of year (Table 1A) and proportional frequency of *S. fremontii* var. *inexpectatus* declined from 8.5% in 2016 to 3.1% in 2020 in those plots where it occurred. Despite this, there were no differences among

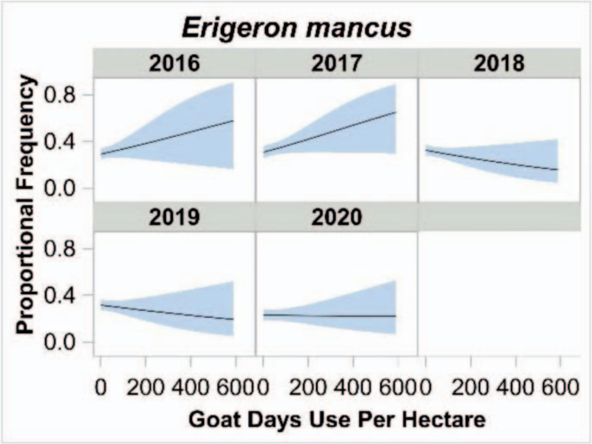

FIG. 5.—The proportional frequency of *E. mancus* occurrence in relation to goat pellet counts, expressed as goat days use per ha, for each of the five study years. Values are LS means (dark blue lines) and the 95% confidence interval (light blue shading). Proportions are estimated at mean or neutral recreational use

years, likely due to small sample sizes (Fig. 3). An interaction existed between year and goat days use (Table 1A), but the differences among years were not ecologically meaningful. In addition, an interaction existed between recreational use and goat days use (Table 1A) in that proportional frequency of *S. fremontii* var. *inexpectatus* was negatively related to goat days use in low recreational use areas ($P = 0.0080$; Fig. 6), which is primarily where it occurred.

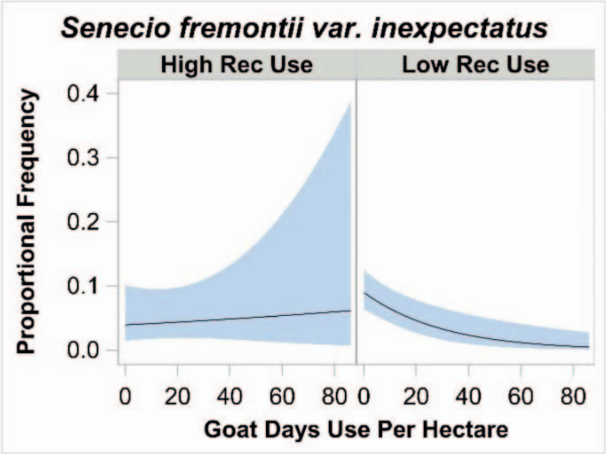

FIG. 6.—The estimated proportional frequency of *S. fremontii var. inexpectatus* in high and low recreational use areas plotted in relation to goat pellet counts, expressed as days use per ha. Values are LS means (dark blue lines) and the 95% confidence interval (light blue shading). Proportions are estimated at mean year

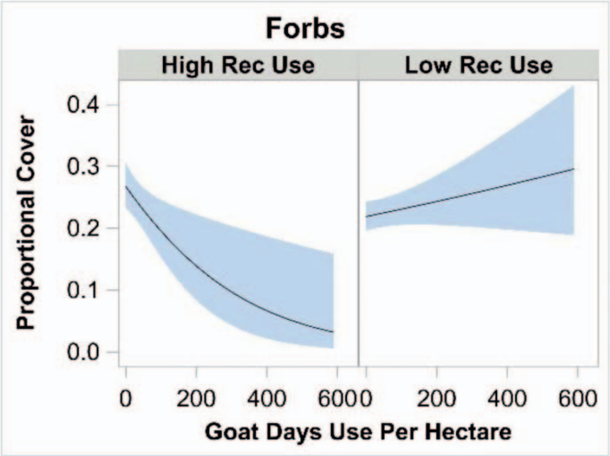

FIG. 7.—The estimated proportional cover of forbs in high and low recreational use areas plotted in relation to goat pellet counts, expressed as days use per ha. Values are LS means (dark blue lines) and the 95% confidence interval (light blue shading). Proportions are estimated at mean or neutral recreational use

RESPONSE OF FORB, GRAMINOID, NONVASCULAR PLANT, AND LITTER COVER

Forb cover was much higher than either graminoid or nonvascular plant cover in the monitoring sites (Fig. 3). There was an effect of year (Table 1B) in that forb cover showed an almost continuous decrease over time, *i.e.*, 2016 (30.1%) > 2017 (26.4%) > 2019 (22.4%) > 2018 (20.3%) and 2020 (18.2%). An interaction existed for year and recreation (Table 1B). In 2016 high recreational use sites had the highest forb cover, but in 2020 high recreational use sites did not differ from low recreational use plots and had the lowest cover (Fig. 4). An interaction existed between recreation and goat days use (Table 1B) in that the relationship of forb cover to goat days use was neutral in low recreational use areas and negative in high recreational use areas ($P = 0.0107$; Fig. 7).

Graminoid cover showed an overall effect of year (Table 1B) in that cover was higher in 2016 (5.1%) than in 2017 (4.0%), 2018 (3.4%), 2019 (3.7%), and 2020 (3.6%). In addition, an interaction existed between goat days use and recreation (Table 1B), but the differences were not ecologically meaningful.

Nonvascular plant cover showed an overall effect of year in that mean proportional cover across all monitoring sites was higher in 2016 (2.9%), 2017 (1.9%), 2018 (1.9%), and 2019 (2.0%) than in 2020 (1.4%) (Table 1B, Fig. 3). In addition, a main effect of recreation existed (Table 1B) in that the highest nonvascular plant cover was in low recreational use plots (3.0%) and the lowest cover was in high recreational use plots (1.3%) (Fig. 4). There was no effect of goat days use.

Litter cover showed the opposite trend of forb, graminoid, and nonvascular plant cover. There was an overall effect of year in that mean proportional cover across all monitoring sites was lower in 2016 (12.6%) than in 2017 (18.3%), 2019 (19.5%), and 2020 (20.3%). Litter cover in 2018 (21.7%), the driest year, was higher than in all other years except 2020 (Table 1B, Fig. 3). A year by recreational use interaction existed (Table 1B) in that litter cover was lowest in high recreation use areas in 2016. In 2018 litter cover in low and high recreational use was greater than in low and high recreational use in 2016 (Fig. 4). There was no effect of goat days use.

RESPONSE OF BARE SOIL, PAVEMENT, ROCK AND INEFFECTIVE GROUND COVER

Bare soil cover showed an effect of year in that 2018 (8.9%) and 2020 (9.3%) had higher bare soil than 2019 (7.5%) (Table 1C). A year by recreation interaction existed (Table 1C) in that there was lower bare soil in 2016 in high recreational use plots and in 2019 in low use recreational plots, than in 2020 in high recreational use plots (Fig. 4). There were no effects of goat use days.

Pavement cover differed among years and mean proportional cover across all monitoring sites was higher in 2019 (20.3%) and 2020 (20.2%) than in 2016 (13.3%), 2017 (12.7%), and 2018 (14.0%) (Table 1C, Fig. 3). There was no effect of recreation. There was a trend towards an effect of goat use (Table 1C) in that goat days use was positively related to pavement cover, but the model estimates were not significant.

Rock cover showed an effect of year in that cover was highest in 2020 (32.4%) and lowest in 2016 (27.9%) (Table 1C, Fig. 3). There was no effect of recreation. There was a year by goat days use interaction (Table 1C). The model estimates indicated negative relationships with goat days use in 2016, 2017 and 2018 and positive relationships in 2019 and 2020 but they were not significant.

Ineffective cover (the combination of bare soil and pavement) increased over the 5 y monitoring period (Table 1C). Ineffective cover was higher in 2019 (24.7%) and 2020 (24.8%) than in 2016 (20.9%) and 2017 (20.8%) (Fig. 3). There was a year by recreation interaction (Table 1C) in that proportion of ineffective ground cover in high recreational use areas was greater in 2020 than in 2016 and 2017 (Fig. 4). In addition, an effect of goat days use existed in that ineffective ground cover increased with increasing goat days use ($P = 0.0138$; Fig. 8).

DISCUSSION

Our analyses revealed significant decreases in proportional frequency of the critically imperiled plant species, *E. mancus*, and in proportional cover of the vascular and nonvasclular plants, particularly forbs, over the 5 y monitoring period. In addition, there were significant increases in proportional covers of litter, rock, pavement, and ineffective ground cover towards the end of the monitoring period. To understand the changes over time and develop meaningful management strategies, the effects of weather and climate, recreational use, and goat days use need to be considered.

EFFECTS OF WEATHER AND CLIMATE

The monitoring was conducted during a relatively dry period and regional weather and climate patterns likely influenced some of the observed patterns. In San Juan County, Utah, which contains the La Sal Mountains, annual and growing season temperatures increased, and standardized precipitation-evaporation indices became more negative during the last two decades compared to earlier decades (WestWideDroughtTracker, 2021). Ongoing climate change may exacerbate any effects of recreational and mountain goat use on species of conservation concern and alpine plant communities (Hammitt *et al.*, 2015; Gutzwiller *et al.*, 2017). Recent down-scaled climate projections evaluated the change in temperature and precipitation for the Colorado Plateau and Arizona-New Mexico Plateau ecoregions for the near- (2020–2050) and longer-term (2070–2100) relative to 1980–2010 using representative

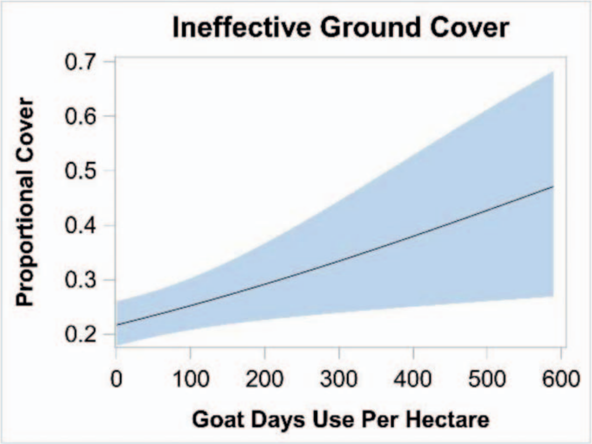

FIG. 8.—The estimated proportional of ineffective ground cover in relation to goat pellet counts, expressed as goat days use per ha. Values are LS means (dark blue lines) and the 95% confidence interval (light blue shading). Proportions are estimated at mean or neutral recreational use

concentration pathways (RCPs) of 8.5 (Chambers *et al.*, 2017). Projections indicate temperature increases of 1 to 3 C by 2050 and between 4.8 and 5.8 C by the end of the century (Chambers *et al.*, 2017). Changes in precipitation are more difficult to model, but the ecoregional projections indicate increases of about 10 to 15% in mean annual precipitation in the near-and short-term, with decreases from April through June and increases from July through September (Chambers *et al.*, 2017). Increases in precipitation may not result in increased soil water availability, because as temperatures rise potential evapotranspiration also rises (Palmquist *et al.*, 2016). In addition, the alpine growing season in this area is typically June through August and any precipitation increases may come too late in the season to benefit plant growth and reproduction. Future weather patterns are projected to be more variable than in the past, and the frequency and severity of droughts are projected to increase in the southwest (Cook *et al.*, 2015; Lehner *et al.*, 2018). In this region, the low and variable precipitation during the monitoring period is likely to be more common in coming decades.

Alpine species are being affected by changes in climate suitability and the potential for upwards migration. Most alpine plants require two growing seasons to produce seeds—floral bud initiation in the first season and seed maturation in the second (Körner, 1999)—and seedling establishment is highly dependent on weather conditions (Chambers *et al.*, 1995). Consequently, reproduction of obligate seeders is highly dependent not only on potential changes in climate suitability for individual species, but also on the interacting effects of changes in temperature and precipitation.

TRENDS IN PLANT SPECIES OF CONSERVATION CONCERN

Proportional frequency of *Erigeron mancus* decreased significantly at the end of the monitoring period. In addition, proportional frequency of *S. fremontii* var. *inexpectatus* declined from 8.5% in 2016 to 3.1% in 2020, although there were no differences among years likely due to small sample sizes. Prior research evaluated population trends of *E.*

mancus along an elevational transect that was located on a mountain ridge in the study area and surveyed in 2009 and 6 y later in 2015 (Fowler and Smith, 2010; Fowler *et al.*, 2018). Descriptive and inferential statistics ($\alpha = 0.05$) were used to evaluate plant densities, patch width, and species centroid elevations. The authors found *E. mancus* population density and distribution did not change significantly from 2009 to 2015 and concluded the population was stable, although they noted that the species was most abundant in alpine meadow habitat with greater moisture availability in both survey years (Fowler *et al.*, 2018). The recent declines in proportional frequency of the two critically imperiled species may be an early warning of population instability and indicate that further monitoring is warranted.

EFFECTS OF RECREATION AND MOUNTAIN GOATS ON ALPINE PLANT COMMUNITIES AND SPECIES OF CONSERVATION CONCERN

Erigeron mancus was negatively related to high recreational use at the end of the monitoring, and *S. fremontii* var. *inexpectatus* was negatively related to goat days use in low recreational use areas, which is primarily where this plant species occurs. The number of mountain goats recorded at camera monitoring sites suggests the use of pellet counts to indicate goat days use may have underestimated the effects of the mountain goats on the plant species and communities. The susceptibility of the plant species of conservation concern to recreational and mountain goat use is influenced by their structural and reproductive characteristics. *Erigeron mancus* is a perennial, taprooted species that reaches 2 to 7 cm in height and has erect stems and leaves at the base of the plant, and *S. fremontii* var. *inexpectatus* is a perennial, tap rooted species that can reach 10 to 20 cm in height and has erect leafy stems (FNA, 2021). *Androsace chamaejasme* ssp. *carinata* is a perennial species that forms loose or dense mats (FNA, 2021). All three species reproduce from seed. Prior studies indicate forbs with erect, caulescent stems and elevated inflorescences, such as *E. mancus* and *S. fremontii* var. *inexpectus,* tend to be more sensitive to recreational trampling effects than turf-forming graminoids, or forbs with rosette growth forms, such as *Androsace chamaejasme* ssp. *carinata* (Kuss, 1983; Cole and Monz, 2002). We found no published information on effects of grazing on the plant species of conservation concern in our study, but other species in the Asteraceae experienced significant reductions in growth and reproduction due to grazing by mountain goats (Pfitsch, 1981; Pfitsch *et al.*, 1983). The growth forms of the plant species of conservation concern make them accessible to grazers and evidence of grazing by mountain goats, pika and other wildlife indicate that all of the species are palatable. Field observations show that *S. fremontii* var. *inexpectus* is often heavily utilized, especially in the late summer/fall when it is flowering. Constraints on establishment from seed in harsh alpine ecosystems may decrease recovery of these species after recreation or mountain goat disturbance in trail and grazed environments (Chambers *et al.*, 1990; Chambers *et al.*, 1995).

Proportional cover of forbs, which had the highest cover of any life form, declined almost continuously over the monitoring period. High recreational use in combination with high mountain goat use had negative effects on forb cover. In contrast, litter cover was lowest at the beginning of the study, when both graminoids and forbs had higher cover, and greatest towards the end, when graminoids and forbs were low. Effects on vegetation due to trampling are often attributed to recreation, but effects of livestock (cattle, sheep, and goats) are often more severe due to multiple trails and wallows (reviewed in Cole, 2004) and those of mountain goats are likely to be similar (Houston *et al.*, 1994). Trampling can cause reductions in plant height, stem length and leaf area, as well as in the number of plants that flower, the number of flower heads, and seed production (Liddle, 1997; Cole and Monz, 2002). Reduced height and leaf area can decrease a plant's photosynthetic potential and result in depleted carbohydrate reserves, productivity, and reproduction (Hartley, 1999). Broken off stems from trampling and plant mortality may result in increased litter. In addition, drier conditions, as observed towards the end of the monitoring period, may further increase the amount of litter via mortality of stems and leaves.

Ungulate grazing affects alpine plant species and vegetation through the processes of foraging and deposition of feces and urine as well as trampling (Augustine and McNaughton, 1998). Mountain goats are generalist herbivores that eat a diversity of vegetation (Saunders, 1955; Hibbs, 1967; Laundré, 1994). A summary of ten foraging studies on feeding habits of mountain goats indicated that the average summer diet included 52% grass, 30% forb, and 16% shrub (Laundré, 1994). In spring, goats foraged on newly growing herbaceous plants (Dailey *et al.*, 1984), whereas in winter, the average diet shifted to a higher proportion of grasses and shrubs (Laundré, 1994). Grazing by mountain goats has been shown to affect growth and reproduction of herbaceous alpine forb species. Piper's bellflower (*Campanula piperi*), Webster's senecio (*Senecio neowebsteri*), and Olympic Mountain aster (*Eucephalus paucicapitatus*), showed reductions of 20% to 60% in leaf length, flower production, and growth (cover and biomass) when grazed by mountain goats, and mountain goat grazing removed 65% of aboveground net production of Webster's senecio (Pfitsch, 1981; Pfitsch *et al.*, 1983). Alpine skypilot (*Polemonium viscosum*) in krummholz and alpine tundra habitats experienced complete loss of annual seed production in the current year and up to 80% loss of net seed production over a three-year interval as a result of ungulate herbivory (Galen, 1990). Plants showed no capacity to compensate for losses in reproductive capacity due to grazing (Galen, 1990). Alpine plants may be particularly vulnerable to herbivory, because of the inability to allocate new meristems to flowering in a compensatory manner as a result of cold temperatures and shorter growing seasons. Plant mortality coupled with reduced seed production and seedling establishment following recreational and mountain goat disturbance can have a net effect of decreased vegetation cover (Aho and Weaver, 2003; Houston, 1994).

EFFECTS OF RECREATION AND MOUNTAIN GOATS ON INEFFECTIVE GROUND COVER

Ineffective ground cover (the combination of bare soil and pavement cover) was greatest in high recreation use sites at the end of the monitoring period and increased with increasing goat days use. The effects of trampling on soils interact with those on vegetation. Trampling can compact soils and reduce porosity, decreasing water-holding capacity (except in some coarse-textured soils) and water infiltration rates (Cole, 2004; Hammitt *et al.*, 2015). Soil compaction effects are exacerbated by abrasion and loss of organic soil horizons, which shield underlying mineral soil horizons from excessive compaction and erosion. These physical soil changes alter soil chemistry and biota and also inhibit seed germination and plant growth (Alessa and Earnhart, 2000). The use of established trails with reduced or no vegetation can loosen soil particles, resulting in detachment and transport by erosive agents such as wind and water (Wilson and Seney, 1994; DeLuca *et al.*, 1998). Classified soils in the study area are Meredith stony loams, have large rock fragments at the surface and shallower soils, and may be particularly susceptible to detachment and erosion (University of California, Davis and USDA Natural Resources Conservation Service, 2021). Proliferation of user-created trails along hiking routes where a trail tread is never constructed can reduce vegetation, increase erosion over larger areas (Barros and Pickering, 2017), and increase the difficulty of restoration (Ebersole *et al.*, 2002).

CUMULATIVE EFFECTS AND MANAGEMENT CHALLENGES

The cumulative impacts of climate change, recreational use, and introduced mountain goats on plant communities and species of conservation concern in the La Sal Mountains may increase over time without management action. Continued downward trends in critically imperiled species, including the endemic *E. mancus* and *S. fremontii* var. *inexpectatus* (NatureServe, 2021), may reduce the capacity for reproduction and population maintenance. Further declines in forb cover and likely changes in plant community composition may affect the species that depend on them, such as marmots and pikas, as well as the pollinators necessary for seed production. The mountain goat population also may decline in the long-term, if numbers continue to increase and the carrying capacity of the alpine habitat is exceeded. A reduction in summer forage quality or amount due to ongoing climate change and prolonged drought can result in a decrease in the body reserves needed to survive the winter season (Kohli, 2014). Poor forage quality in winter is typical of alpine and subalpine ecosystems and high energetic costs in the cold environment may reduce already low reproductive rates and decrease animal survival (Kohli, 2014).

To better understand the interacting effects of climate change, recreational use, and introduced mountain goats, the monitoring design could be updated. Information on habitat use, individual survival, and population dynamics could be obtained by collaring additional mountain goats and tracking their movements, and by more closely monitoring herd numbers. The use of pellet counts to indicate goat days use may underestimate the effects of goat use on plant species of conservation concern and communities, and more rigorous camera monitoring may provide more accurate data. More detailed information on the types of vegetation and their patterns on the landscape could be obtained and related to spatial patterns of use by both mountain goats and recreationists. Additional monitoring locations with *S. fremontii* var. *inexpectatus* could be installed to better evaluate population trends of this critically imperiled species, and repeat photography and erosion pins could be used to examine effects of trails and heavy use by mountain goats on vegetation condition and soil erosion.

Management complexity arises because of the different missions of the two agencies involved. The management goals of UDWR are to: (1) establish sustainable populations of mountain goats by utilizing suitable habitat within the state to create and foster individual populations; (2) provide good quality habitat for healthy populations of mountain goats; and (3) provide quality opportunities for hunting and viewing mountain goats (UDWR, 2018). The mountain goat herd unit plan for the La Sal Mountains (UDWR, 2019) includes direction related to plant species of conservation concern; specifically, vegetation monitoring will be coordinated by UDWR and the USDA Forest Service to evaluate potential effects and determine appropriate management actions to address documented adverse impacts. The USDA Forest Service manages alpine ecosystems in the La Sal Mountains to maintain a healthy, vigorous condition and to avoid severe ground disturbance that would affect the perpetuation of alpine vegetation considering its potential for slow recovery (USDA Forest Service, 1986). There is also direction to maintain plant species of conservation concern and manage their habitats to reduce the potential of these species becoming threatened or endangered. The USDA Forest Service manages the RNA in the La Sal Mountains to protect ecosystem structure and function as well as maintain and protect natural diversity. This type of "dual mandate" of the USDA Forest Service to maintain an unmodified condition in the RNA and yet allow people to access the larger area to experience nature has often been described as a significant management challenge (Hammitt *et al.*, 2015). To maintain ecologically resilient alpine ecosystems in the La Sal

Mountains, adjustments in mountain goat numbers and recreational use may be needed. An updated monitoring plan and continued monitoring of plant communities and species of conservation concern can provide the basis for adaptive management.

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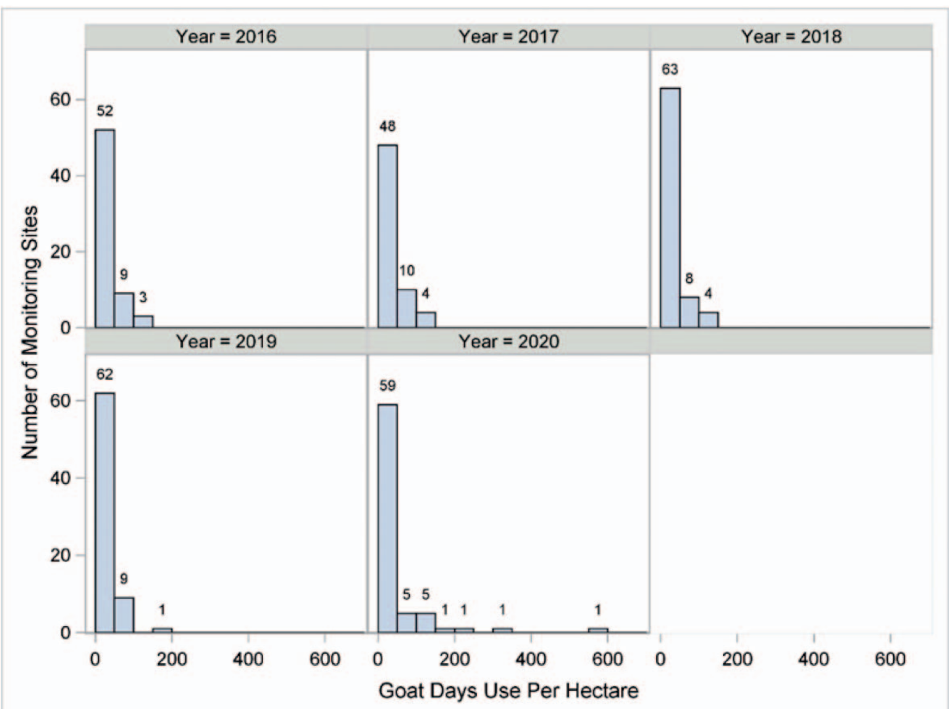

APPENDIX. 1.—The number of monitoring sites in which goat pellets were observed and the numbers of pellets that were observed at the monitoring sites in 50 count increments. The number above each bar indicates the number of monitoring sites included in each increment.