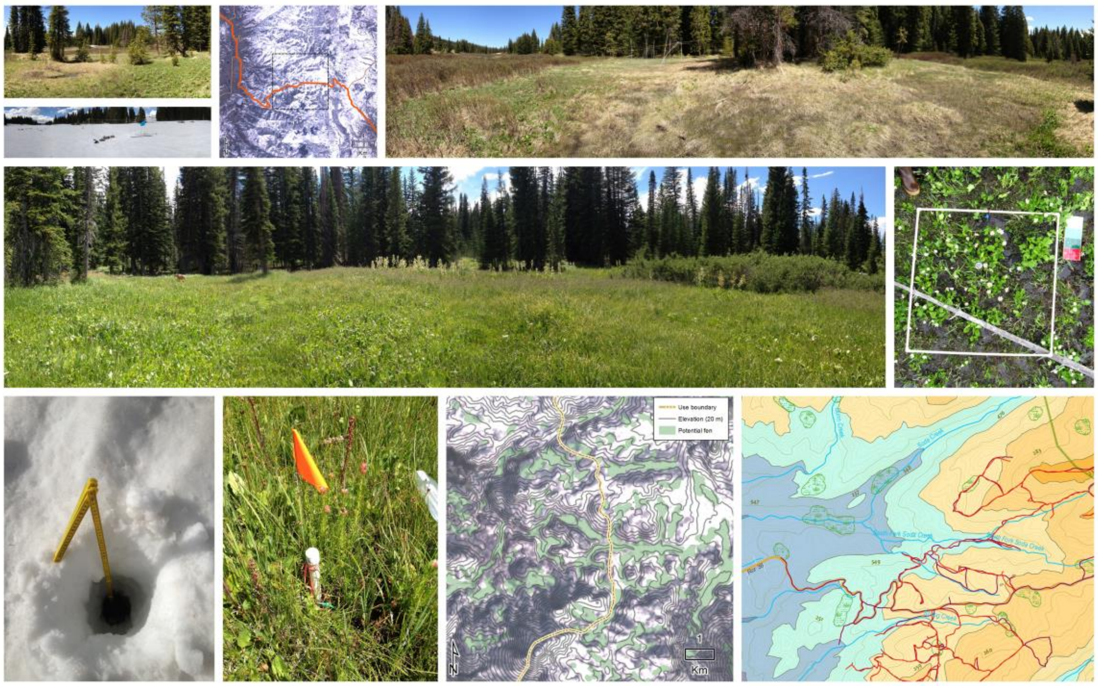
EVALUATING SNOW COMPACTION EFFECTS TO FEN WETLANDS ON RABBIT EARS AND BUFFALO PASS OF THE ROUTT NATIONAL FOREST



Final Research Report

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Summary

Fens are a high value resource on the Routt National Forest, important for their ecological functions and biodiversity. Motivated by concerns about potential negative impacts from winter recreation activities such as snowmobiling on fen condition and functioning, we began a research and monitoring study in late 2008 aimed at assessing effects from snow compaction on peat soil temperature and several dependent ecological variables including plant production, decomposition, and phenology. This report summarizes results and conclusions from our research. To provide context for these analyses, we also present unpublished data from winter recreation impact studies on fens located in the Telluride Ski Area (Grand Mesa Uncompahgre National Forest) in Southwest Colorado.

We employed analyses at both the field and landscape scales. Working in a series of fens near Rabbit Ears Pass and Buffalo Pass on the Routt National Forest, we contrasted soil temperatures measured *in situ* with temperature loggers in plots subjected to snow compaction and uncompacted controls. Potential effects from snow compaction on vegetation production and decomposition processes were assessed using clipping plots and litter decomposition bags installed in study area plots. Observational assessments of vegetation composition and phenology were made in compacted and non-compacted locations, along with depth to water table measurements. Lastly, we conducted an analysis of landscape-scale snowpack persistence patterns using GIS and remote sensing data sets.

While we observed high interannual and site-to-site variability in soil temperatures, results from Routt NF study sites revealed no statistically significant differences in the temperature of peat soils in compacted and non-compacted areas. Mean wintertime temperatures were

statistically indistinguishable in compacted and non-compacted sites, and the difference in mean daily soil temperatures during the winter and spring prior to melt-out was less than 1°C. At the Buffalo Pass fen, freezing temperatures were only observed in soils in plots with snow compaction, but no delays in the onset of melt-out due to soil freezing were observed. In contrast, much more pronounced soil temperature effects from snow compaction were documented from the Telluride Ski Area fens, with compacted soils freezing and thawing weeks later in the spring than controls.

Analyses of ecological response variables did not identify any statistically significant differences in areas subject to snow compaction when compared to controls. Aboveground biomass from clipping plots and decomposition from litter bags was highly variable and influenced more by microtopography, water table depth, and variation in plant species composition than snow compaction. Observational analyses of plant phenology also failed to identify differences due to snow compaction. When we controlled for the influence of physiographic variables such as elevation, slope, and aspect, our landscape-scale assessment of the patterns of snowpack persistence, developed using a multi-temporal analysis of Landsat satellite imagery, did not indicate any differences in snowpack persistence in areas with and without motorized winter recreation. Collectively, our analyses span a range of winter recreation types and snow compaction characteristics, including moderate compaction from Nordic skiing (west-side Rabbit Ears Pass), more intensive and frequent snow compaction from snowmobiling and snowcat use (Buffalo Pass and east-side Rabbit Ears Pass), and high intensity and frequency snow compaction from mechanized grooming at the Telluride ski area fens. The differing results suggest that snow compaction effects from winter recreation are strongly conditioned by the frequency and intensity of compaction events.

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Introduction

Fens are groundwater-supported wetlands with perennially high water tables that retard organic matter decomposition, leading to the accumulation of peat (Bedford and Godwin 2003, Mitsch and Gosselink 2007). Although widely distributed in boreal regions, fens in Colorado are generally restricted to high mountain environments with cool and wet climatic conditions (Chimner and Cooper 2003). Fens comprise a small percentage of mountain landscapes, but support many critical ecological functions and are important to local and regional biodiversity, providing habitat for many rare plants (USFS 2005).

Because of their ecological importance, National Forests must address potential threats to wetland resources in their Land and Resource Management Plans and other forest planning documents. A question of particular concern to managers is whether critical habitats like fens are declining in quality or extent (USFS 2007). A variety of anthropogenic stressors negatively affect fens in the region (Chimner et al. 2010, Gage and Cooper 2013), but for many stressors, there is little information from which to evaluate impacts to ecological processes or condition.

The popularity of winter recreation has grown dramatically in recent years, forcing land managers to address impacts in planning and management assessments (USFS 2005). Easy access from the Metro Denver area, high quality terrain, deep snowpack, and proximity to the Steamboat Springs ski area make areas of the Routt National Forest particularly popular with different winter recreational user groups including non-motorized users (backcountry skiers, snowshoers) and snowmobilers. However, potential effects from winter recreation activities on fens remain poorly understood.

Previous research suggests that winter recreation activities may measurably affect wetlands by altering the physical characteristics of snowpacks (Keddy et al. 1979). Compaction-induced changes in peat thermal characteristics may affect the duration of snowpacks, an important factor influencing organisms and ecosystem function (Billings and Bliss 1959, Aurela et al. 2004, Pauli et al. 2013). Snow compaction can negatively affect subnivean space, defined as: “a thermally stable place in which the soil surface temperature remains near 0°C, while the ambient air temperature fluctuates”, which is critical for many small mammals (Halfpenny and Ozanne 1989, Aitchison 2001). Effects may also include changes in soil temperature that indirectly affect ecological processes such as plant production and decomposition, phenology, or growth (Fahey et al. 1999, Cooper and Arp 2002, Crimmins and Crimmins 2008). Over time, changes may alter patterns of community composition, possibly to the detriment of rare species.

To address resource management concerns about potential impacts from winter recreation activities on fens, and to address monitoring requirements in amendments to the Forest Plan (USFS 2005), we initiated a research and monitoring study in late 2008, with funding provided by the USFS through a co-operative agreement with Colorado State University. This report summarizes work conducted as part of this agreement.

Monitoring objectives

A key recommendation from the Winter Recreation Management and Routt Forest Plan Amendment (USFS 2005) is that fens should be monitored to assess impacts from winter recreation use. Towards this goal, we identified potential responses known or hypothesized to occur due to winter recreation. Specifically, we sought to identify impacts from snow compaction on the thermal characteristics of soils and document any effects on vegetation or ecosystem function. Specific questions we evaluated included:

- Does snow compaction associated with different winter recreation activities affect soil temperature in fens?
- Is there evidence of altered ecological processes such as plant production or decomposition in fens experiencing snow compaction?
- If altered peat soil thermal regimes result from snow compaction, does this affect the growing season length for plants and dependent processes like plant phenology?
- At a landscape scale, does snowpack in Routt NF fens persist longer in areas subject to motorized snow compaction than in areas without snow compaction?

Methods

We used several approaches to evaluate potential effects of winter recreation activities on fens. First, an observational approach was taken with a set of randomly sampled sites located in fens subject to snow compaction and fens where management designation excludes it. Second, we intensively instrumented a fen in an area managed under a special use permit for snowcat-guided skiing and dispersed snowmobile use. Here we made measurements at points compacted from snowcat and snowmobile use, and compared these to uncompacted control points. Third, we implemented a manipulative experiment in the 2012 water year to quantify the effects of experimental snow compaction from Nordic skiing on soil thermal regime. Lastly, we performed an observational remote-sensing assessment of broad-scale snowpack persistence to quantify whether snowpack in fens open to motorized recreation persisted longer than non-motorized areas.

Assessment area

Our assessment area included the Routt National Forest used for winter recreation along Highway 40 near Rabbit Ears Pass and on the Buffalo Pass Road (Forest Service Road 60). This area is a primary staging area for winter recreationists and experiences high levels of snowmobile use and snow compaction (Keinath and McCumber 2007). The Rabbit Ears Pass area supports fens in management zones open to and closed to motorized use, providing an opportunity to evaluate fen conditions under these different management regimes.

In late fall 2008, we selected four fens in the vicinity of Rabbit Ears Pass, two each in areas open and closed to snowmobiling. Four additional fens were instrumented near Rabbit Ears Pass in 2009. Separate motorized and non-motorized designated zones occur on either of Rabbit Ears pass (Figure 1). Use in the motorized zone includes dispersed snowmobiling along with guided commercial trips. Outings are staged from parking areas along Hwy 40, with use radiating to the north and south. Nordic skiing and snow shoeing are popular in the non-motorized zone west of Rabbit Ears pass, with most use concentrated along established trails.

We also established an additional site (Buffalo Pass fen) near Buffalo Pass (Figure 1). A company operating under a special-use permit with the USFS operates a snowcat guide service for skiers in the area. Snowcat operators groomed a path through the Buffalo Pass fen on at least a daily basis during the operating season, typically running from mid-December to mid-

April. Trails groomed by the snow cats were also regularly used by dispersed snowmobilers and skiers.

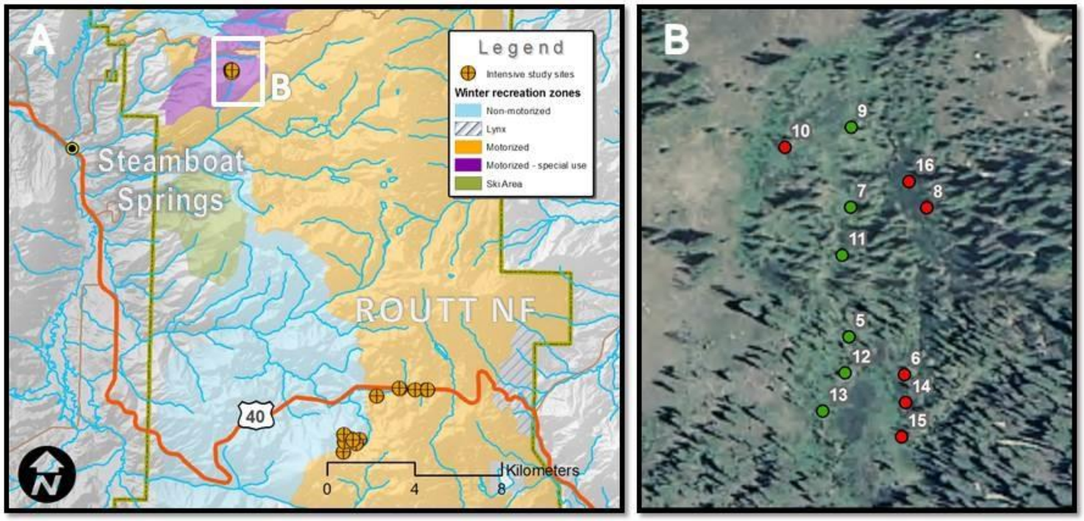


Figure 1. Locations of monitoring sites (panel A). The Buffalo Pass site (inset box; panel B) showing motorized (green) and non-motorized (red) plots.

Field data and analyses

The primary effects of snow compaction we hypothesized are due to changes in snow thermal characteristics and its effects on peat soils. To measure soil temperature at each instrumented site we installed iButtons (DS1921G; Maxim, Inc.), which are self-contained data-logging temperature sensors with a manufacturer-stated accuracy of ± 0.5 ^{o}C (Hubbart et al. 2005, Lundquist and Huggett 2008). Temperature measurements served two functions. The first was to provide continuous measurements of peat soil temperature, the key physical response measure in our analysis. In addition, shallow sensors provide a clear indication of the timing of snowpack melt-out (Lundquist and Lott 2008). Peat soil temperatures were monitored at three depths (5, 20, 35 cm) in 5 fens in 2009: the Buffalo Pass fen and four fens near Rabbit Ears Pass. Additional sensors were added in 2010 and 2011, to replace failed sensors and increase within-site sampling at the Buffalo Pass fen. To allow for more extensive spatial sampling, a single iButton installed at 20 cm depth was used in later installations.

Soil temperatures in snow machine influenced and control locations were examined using time series temperature plots. We used t-tests to statistically contrast mean temperatures during key index periods (winter, spring melt-out, summer). To evaluate differences in the slope (rate) of temperature changes during the dynamic period of spring melting, we used an analysis of covariance (ANCOVA). Inflection points in soil temperature time series following the loss of snow cover and peak summertime soil temperatures were used to define and extract a subset of data. To better satisfy assumptions of linearity, we square root-transformed these data before analysis. Compaction effects were assessed by evaluating the interaction term between snow compaction treatment and date.

At each site instrumented with temperature probes, we established a nested plot design for field sampling. A circular 100 m^2 plot was centered near soil temperature sensors, with smaller circular subplots nested within the macro plot (Figure 2). Water table depth was measured during field visits via the use of shallow fully slotted groundwater monitoring wells. This framework was also used for collection of supplementary data sets like plant production and decomposition.

In June of 2009, we installed litter decomposition bags constructed using homogenized plant litter (primarily *Carex utriculata*) collected from a study area fen. Oven-dried material was coarsely broken down to allow thorough mixing and added to woven plastic mesh bags sealed with an impress sealer. Bags were weighed before installation at a depth of approximately 5 cm in the field. A subset of litter bags were collected in October of 2009 for mass loss analysis, while the remaining litter bags were collected during the Fall of 2010. Additional litter bags were installed in October 2011 and collected in October 2012. Litter bags collected in the field were carefully cleaned and any introduced material (e.g., in-grown roots) was removed before oven drying for 48 hours at 65°C. The mass of remaining litter was measured using a balance and used to calculate the mass loss rate.

Aboveground biomass, an indicator of annual aboveground productivity, was assessed by clipping and collecting all standing vegetation in 0.25 m^2 plots. Samples were oven-dried and weighed to estimate biomass. Samples were collected each field season in late summer. Lastly, ocular estimates of vegetation canopy cover were made for vascular plant species in microplots and subplots.

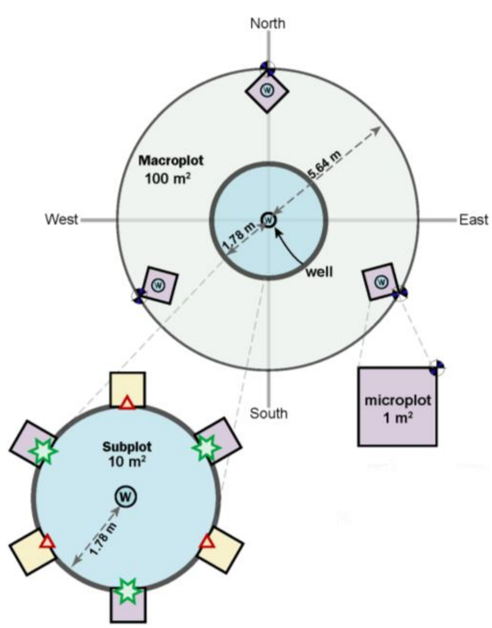


Figure 2. Nested plot design used in analysis.

Digital photographs were taken of microplots using a digital camera and discernible patterns in greenness associated with vegetation growth were identified in compacted and control locations. An 8 megapixel camera was mounted on a telescoping pole and used to capture planimetric images of a square 1 m^2 frame placed on the ground surface. Photographs were taken using automatic white balance and exposure settings in the camera. To provide images on a higher temporal frequency, in 2009, we installed two time-lapse cameras oriented toward the fen ground surface at the Buffalo Pass fen, one in an area subject to compaction and the other in a control area. Images were captured daily from spring to late summer and qualitatively analyzed for evidence of key phenological changes such as the onset of flowering.

Experimental compaction treatment at Rabbit Ears Pass

To evaluate the timing and intensity of snow compaction on fen soil thermal properties, we established experimental plots in three fens located in the non-motorized management area near Rabbit Ears Pass for monitoring during the 2012 water year (Figure 3). The objectives of this experiment were to: (1) measure changes in snow properties associated with different snow compaction starting dates; (2) evaluate changes in soil temperatures and spring melting as a result of compaction treatments; and (3) test for differences in vegetation phenology and standing biomass as a result of the snow compaction treatments.

At each fen, iButton temperature sensors were installed in three tracks representing two experimental compaction treatments and an uncompacted control (Figure 3). Experimental treatments were created by manually compacting snow by repeatedly skiing and walking over tracks until no further compaction could be obtained. The two experimental treatments were differentiated from one another by the timing of initial compaction. Compaction in treatment 1 (T1; early compaction) plots was initiated in late November 2011 after recreational snowmobile use in the Rabbit Ears Pass area was first observed by USFS personnel, and occurred monthly through March 2012. After 1 m of snow had accumulated at the Rabbit Ears Pass SNOTEL site in January 2012, compaction in treatment 2 (T2; late compaction) was initiated and continued through March 2012.

Treatment effects on snow depth and volume were evaluated though snowpack measurements recorded during site visits during the winter of 2011/2012 and measurements made in snow pits in early April, 2012. Sites were revisited following melt-out and temperature data downloaded from iButtons. During visits to the site in the summer and fall of 2012, we manually measured peat soil temperature and water table level and assessed vegetation composition and phenological status of index species. In addition, in early October 2012, remaining litter decomposition bags were retrieved and standing biomass data collected from clipping plots.

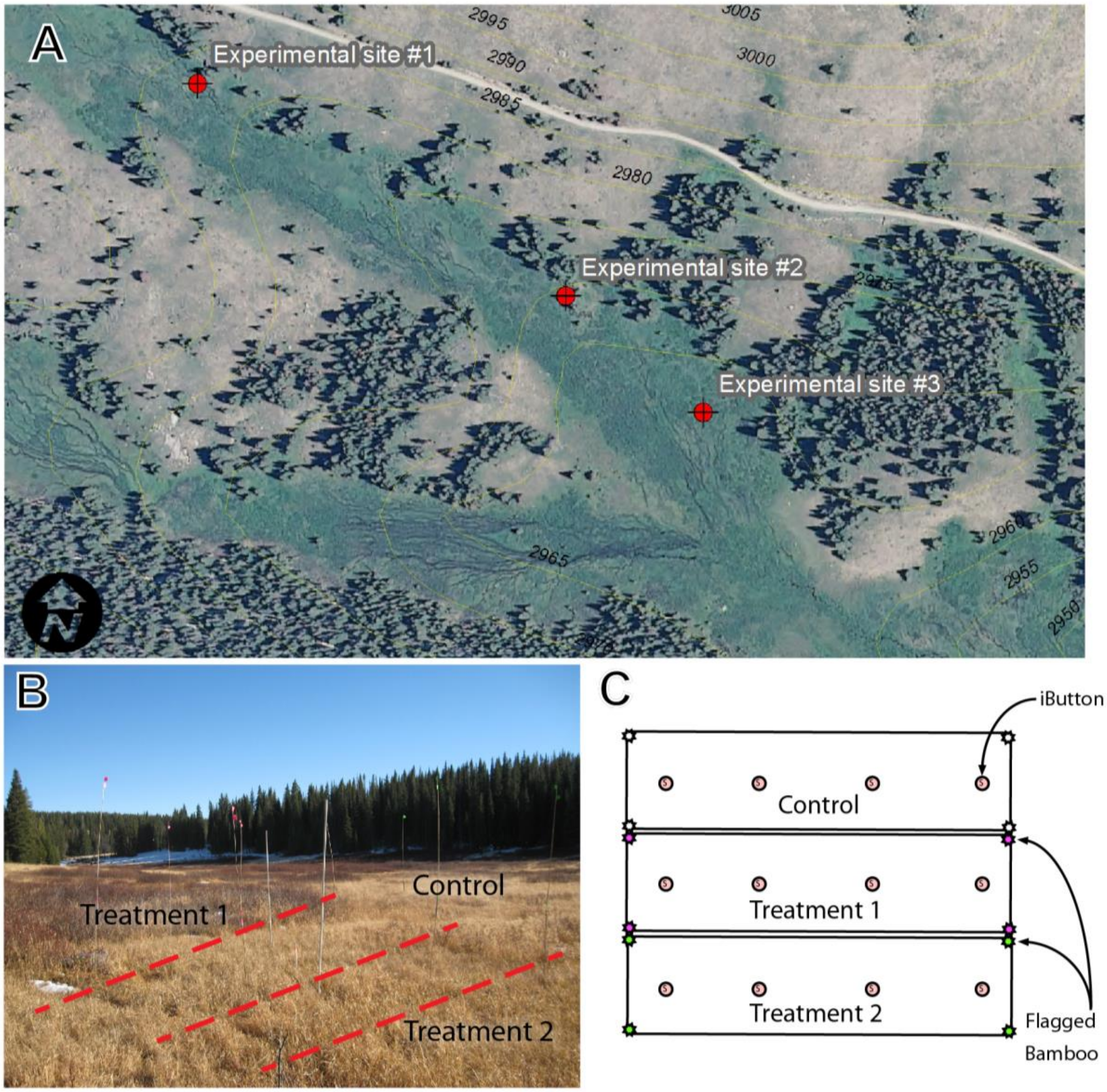


Figure 3. Location of three experimental sites in the non-motorized zone near Rabbit Ears Pass (panel A); Photo illustrating marked tracks at one of the three study sites (panel B); schematic illustration of the layout of control and treatment tracks at the experimental sites near Rabbit Ears Pass (panel C).

Climate data

We obtained climate and snowpack data from SNOTEL sites near the study area (Table 1). We evaluated snow depth and air temperature at both Rabbit Ears Pass and Dry Lake SNOTEL sites. Additionally, we analyzed soil temperature from the Dry Lake site, which are not collected at the Rabbit Ears site.

Table 1. SNOTEL stations used in analyses (Source: http://www.wcc.nrcs.usda.gov/SNOTEL/Colorado/colorado.html).

SNOTEL Site	Dry Lake	Rabbit Ears
Site Number	457	709
Latitude	40 deg; 32 min N	40 deg; 22 min N
Longitude	106 deg; 47 min W	106 deg; 44 min W
Elevation	8400 feet	9400 feet

Remote sensing analysis of snow persistence patterns in motorized and non-motorized areas

One potential effect from snow compaction is a delay in spring snow melt-out, causing a shortened growing season for affected areas. To complement field scale analyses of compaction, we conducted a remote sensing analysis to measure snow persistence in areas with and without motorized winter recreation on Rabbit Ears Pass. The approach is correlative, and examines whether, after controlling for major physiographic factors such as elevation, slope, and aspect, there are differences in snowpack persistence for points located in areas managed with and without motorized winter recreation.

Using a predictive fen distribution model provided by the USFS for our assessment area as a sampling frame, we created 3000 points in potential fen areas in motorized and non-motorized portions of a 100 km^2 assessment area centered on Highway 40. A spatially-balanced equal probability random sampling of the sampling frame was conducted using the ArcGIS 10.1 Geostatistical Analyst extension (Figure 4A, Figure 5). NED-derived attributes were then extracted to the resulting point feature class layer as potential explanatory variables. To ensure that comparisons between motorized and non-motorized zones was based on points sharing similar physiographic characteristics, we performed an agglomerative cluster analysis using rescaled elevation, slope, aspect, and topographic position index values for each of the 3000 points, and compared points within the same cluster but having different motorized snow vehicle uses (Figure 4B, Figure 5). Sample points were placed into six clusters, with the number of clusters chosen by balancing sample point statistical distance from other points evaluated using a dendrogram with the goal of creating an interpretable number of clusters. To ensure that contrasts were made between similar points, the final sample was constrained by only retaining points in the shared elevation range of motorized and non-motorized areas, resulting in a final sample size of 2867 points.

To assess snowpack persistence, we obtained Landsat 5 TM scenes of the assessment area from the US Geological Survey's Global Visualization Viewer (GLOVIS). The available image catalog was browsed for scenes with low (<10%) levels of cloud cover collected during late spring to mid-summer after the snowpack in the assessment area had begun to melt, but prior to its complete disappearance for the season (Figure 4C).

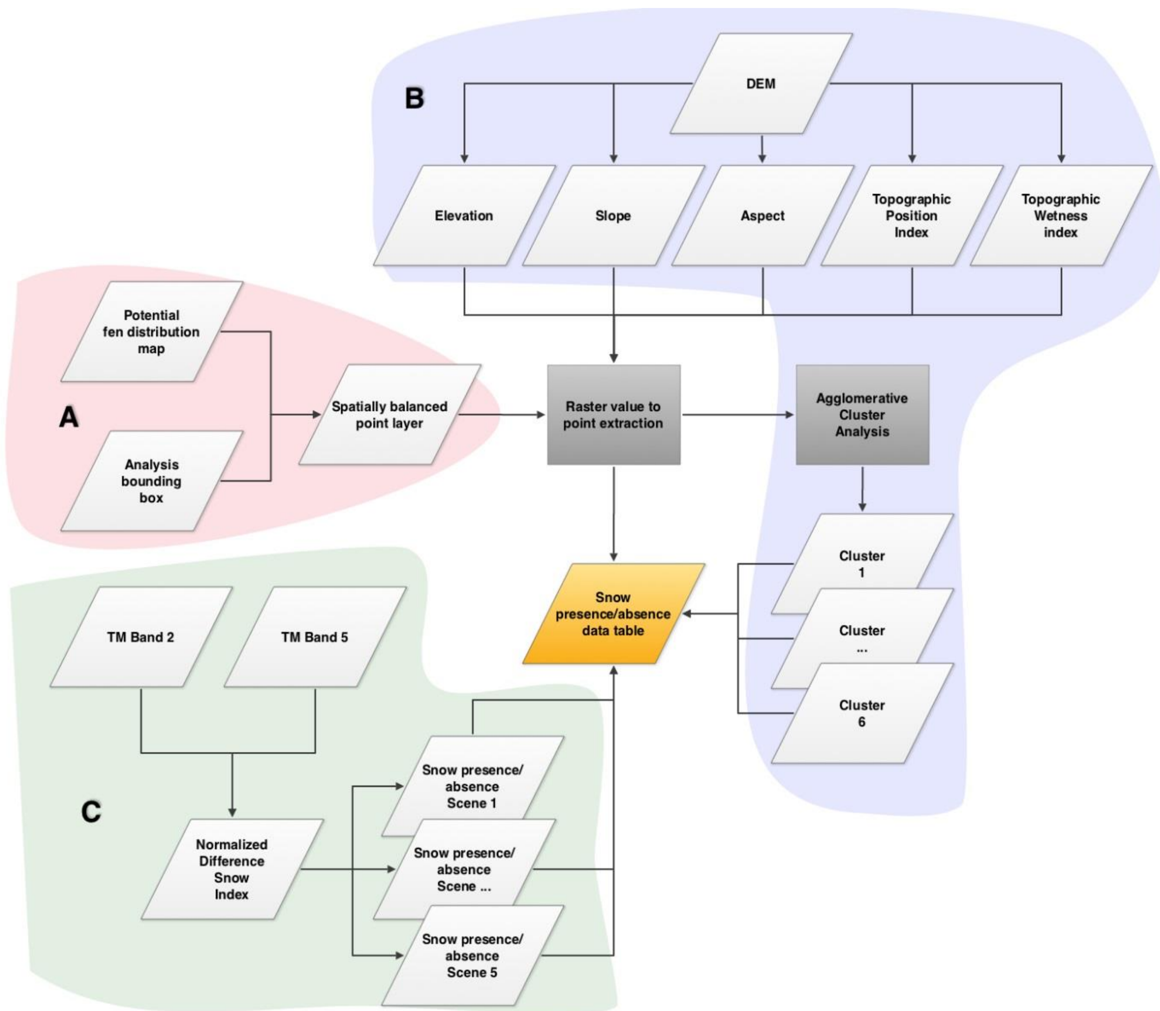


Figure 4. Analysis flow chart. In section A, the USFS potential fen distribution layer, constrained to a 100 km² area centered on Highway 40 near Rabbit Ears Pass, is used as a sampling frame for generation of 3000 spatially balanced random points. Data derived from 15 m digital elevation model (DEM) are clustered using agglomerative cluster analysis in section A, the goal being to provide a means of ensuring that comparisons of snow presence/absence made between points in motorized and non-motorized areas are done on samples with similar physiographic characteristics. In section C, snow presence/absence GIS layers are derived from Landsat 5 TM scenes, and joined with cluster assignments. Lastly, raster values for snow presence/absence, cluster assignments, and physiographic layers are extracted to points and exported for analysis.

Snow is characterized by high reflectance in visible parts of the electromagnetic spectrum, but low infrared reflectance, characteristics that can be used to map snow distribution in multispectral satellite imagery (Dozier and Marks 1987, Dozier 1989, Rosenthal and Dozier 1996). For a given scene (Table 2), we calculated the normalized difference snow index (NDSI), a ratio of the visible and near infrared bands, which in combination with near-infrared reflectance, has been shown to be effective in identifying snow cover (Figure 6)(Riggs et al. 1994). We calculated NDSI following the formula provided by Dozier (1989):

NDSI = (TM Band 2 – TM Band 5)/(TM Band 2 + TM Band 5)

The threshold of 0.4 recommended in previous studies was used to discriminate snow and snow free areas, codified as binary raster files. Snow presence/absence was then assessed for each of the randomly generated points described above, and the resulting attribute table (also containing NED-derived attributes) exported for analysis. For a given cluster, the proportion of points in motorized areas with snow present across multiple Landsat scenes was compared to the proportion of points in non-motorized areas with snow present using a 2-sample test for equality of proportions with continuity correction in the R statistical package. Separate contrasts were made for each cluster group.

Table 2. List of Landsat scenes used in snow persistence analysis.

Sensor	Row/Path	Acquisition date
Landsat 5 TM	35/32	2006-Jun-01
Landsat 5 TM	35/32	2006-Jun-25
Landsat 5 TM	35/32	2008-May-05
Landsat 5 TM	35/32	2009-May-17
Landsat 5 TM	35/32	2010-Jun-28

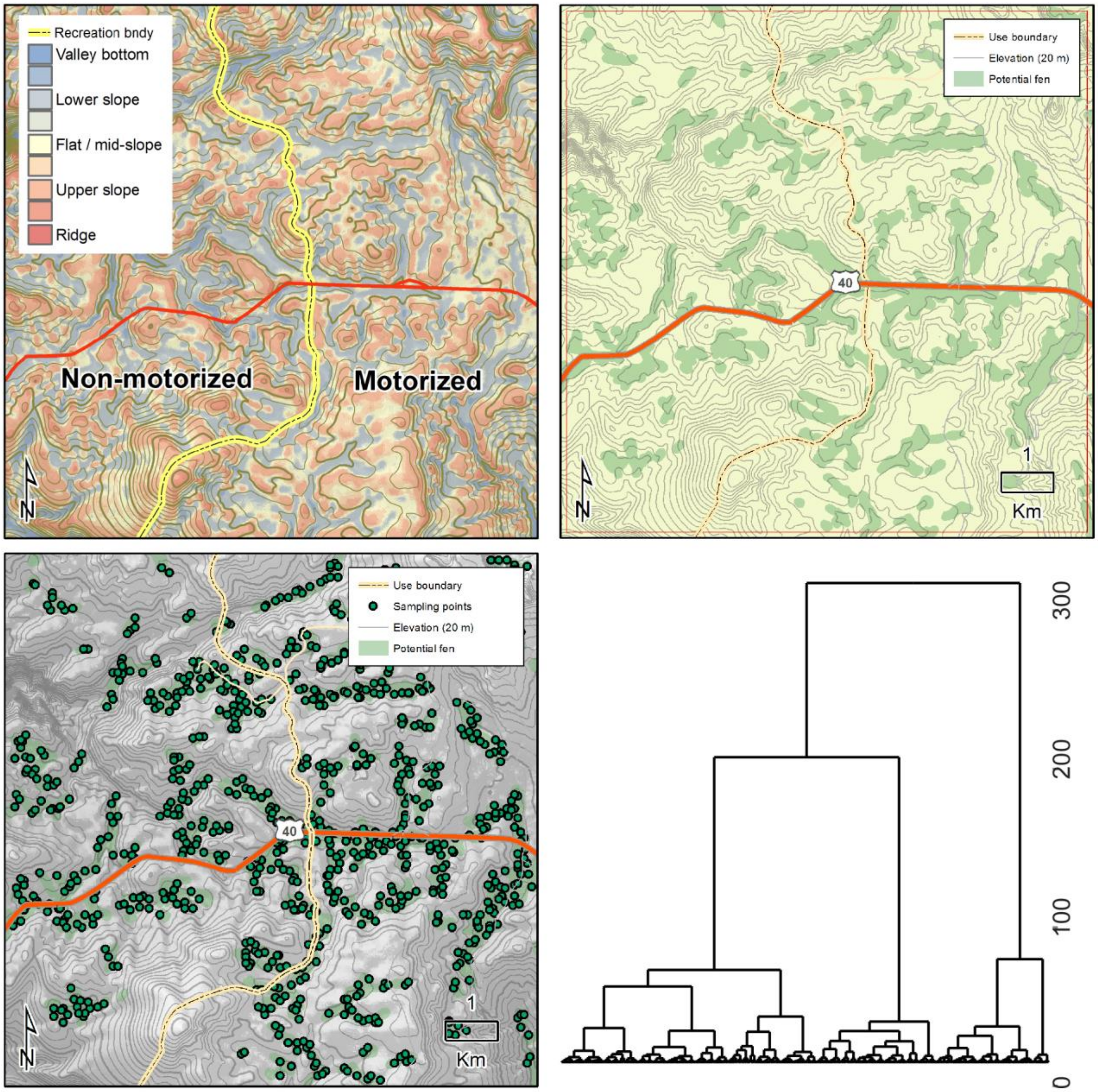


Figure 5. Topographic position index (TPI) for the 100 km² assessment area used in the remote sensing analysis (top-left panel); potential fen model (top-right panel) used in generation of the sampling points shown in bottom-left panel; Dendrogram from agglomerative cluster analysis run on rescaled physiographic variables.

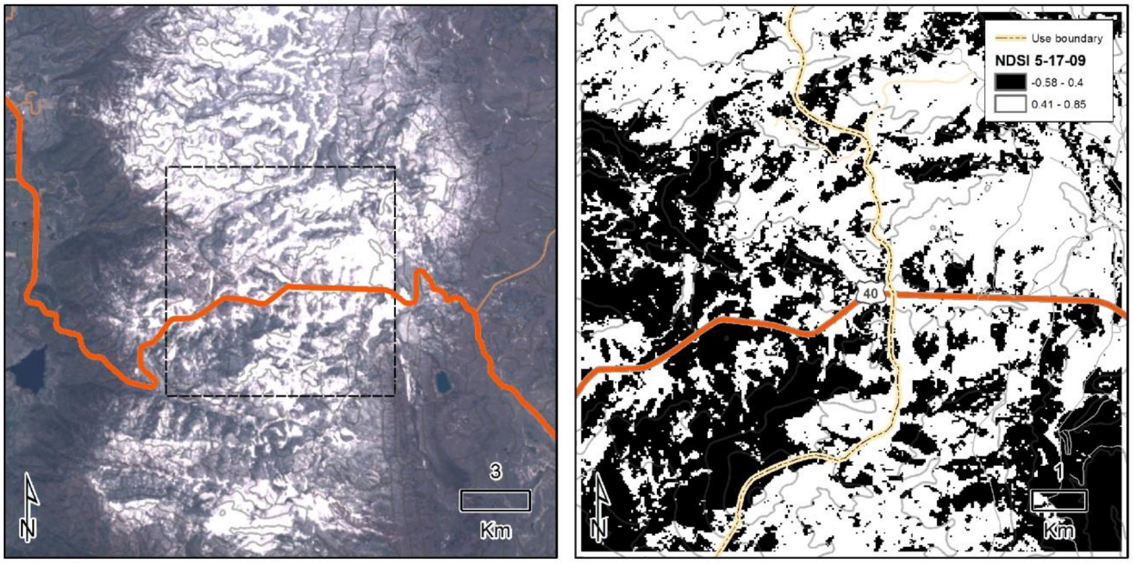


Figure 6. Three-band composite (3,2,1) of Landsat scene from May 17, 2009 (left panel); Close-up of inset area illustrating snow presence/absence mask derived from NDSI (right panel).

Prospect Basin data sets

To provide context for results from our Routt NF analyses, we compared soil temperature data collected in Routt NF fens to that collected in fens in Prospect Basin in the San Juan Mountains, Grand Mesa Uncompahgre National Forest (Cooper and Arp unpublished data). Prospect Basin supports several fens, two of which are bisected by alpine ski runs, and have regular intensive mechanized grooming activities associated with ski run maintenance operations by the Telluride Ski Resort (Figure 7). Peat temperatures in these fens have been monitored using temperature loggers (HOBO, Onset Inc.), with temperature measurements made under groomed trails and in non-groomed control locations.

Figure 7. Fen complex in Prospect Basin (Grand Mesa Uncompahgre National Forest; left panel) with location of Sven Fen indicated. Early-summer photograph of groomed track through a second study site, Cottongrass Fen, illustrating delayed plant development (right panel).

Results

Manual measurements of water table depth at the Routt NF fens indicate that the water table was consistently high (less than 30 cm from the ground surface) through water years with markedly different snowpack conditions. All of the Routt fens examined in this research occur on gentle slopes. The extent and thickness of peat deposits was variable among the Routt fens examined. Fens near Rabbit Ears Pass were generally found as components of wetland complexes supporting riparian and wet meadow communities.

Meteorological data

There was significant year-to-year variability in snow depth, snow water equivalent, and the temporal distribution of snowfall events. The 2011 water year, for example, had record high snowfall and portions of the assessment area did not melt-out until July. In contrast, the 2012 water year was marked by an abnormally low snowpack. Melt out occurred at the Rabbit Ears

Pass SNOTEL site nearly 2 months earlier in 2012 than in 2011 (Figure 8). A similar inter-annual pattern occurred at the Dry Lake SNOTEL data (Figure 9).

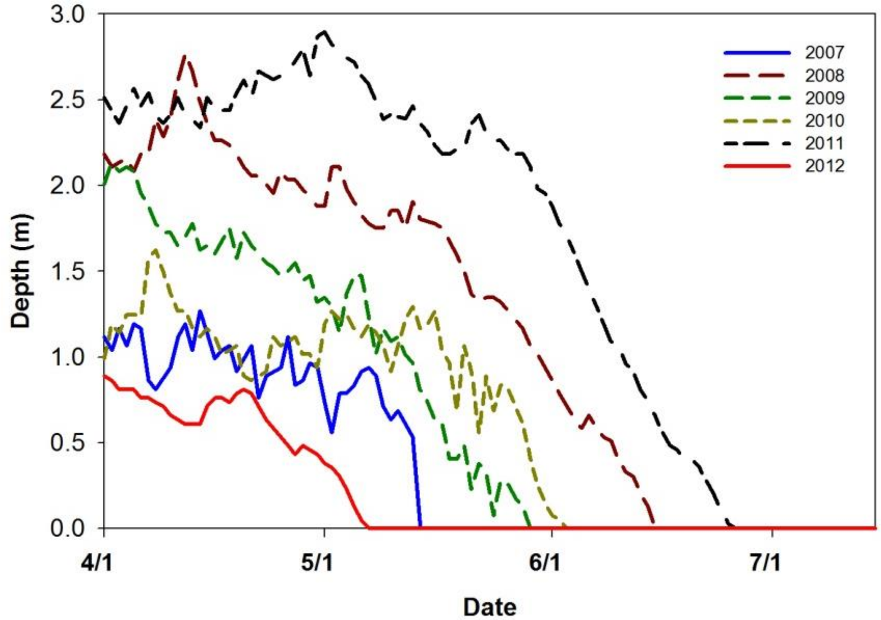


Figure 8. Late season snowpack depth for 2007-2012 for the Rabbit Ears Pass SNOTEL site (site #709).

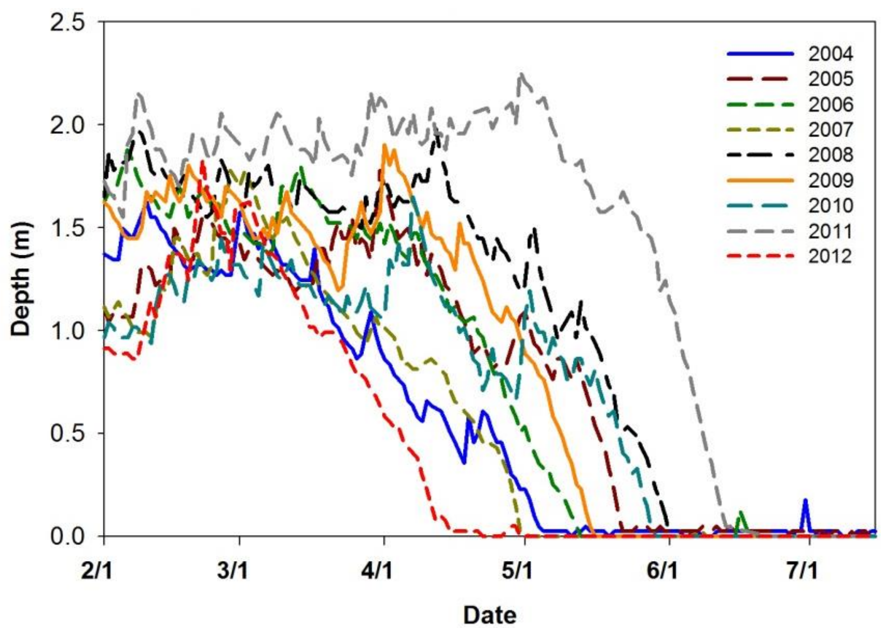


Figure 9. Late season snowpack depth for the years 2004-2012, Dry Lake SNOTEL site (site #457).

Soil temperature

There was considerable variation in soil temperature among sampling locations and with soil depth. Soils near the surface had the greatest diel variation in temperatures following melting but were stable and similar to deeper soils in the winter (Figure 10). In general, near-surface soils experienced greater warming during the summer months than deeper soils. Summertime temperatures of soils located at 25 cm were slightly warmer than those at a depth of 35 cm, but the relationship between soil temperature and soil depth differed among locations, likely due to variation in water table depth. Average peak temperatures occurred in late July in all years. Soil temperature changed the most in the period immediately following snowpack melt-out , with temperatures steeply rising after exposure of the soil surface.

Winter minimum temperatures varied from -0.5°C to 1°C for the motorized and non-motorized areas at both the Buffalo Pass and Rabbit Ears Pass fens. At 20 cm depth, soil temperature in the motorized Buffalo Pass and Rabbit Ears Pass areas ranged from -0.5°C to 0.5°C, while those in non-motorized locations ranged from 0°C to 1°C for the three months preceding the start of melt-out . Mean temperatures at 20 cm depth were lower in motorized than non-motorized locations for both Buffalo Pass and Rabbit Ears Pass sites, but the temperature difference was less than 1°C (Figures 11-14). On a frequency basis, the majority of sensors in both motorized and control areas saw temperatures go to freezing (0°C or below), but the proportion was higher in motorized locations (e.g., 91% and 80% for motorized and control plots at Buffalo Pass). In general, soil temperatures varied more in summer than during winter, but did not show a consistent relationship by treatment. Comparisons of temperature in motorized and control plots were not statistically different in any of the three index periods (winter, spring, summer)(Figure 15).

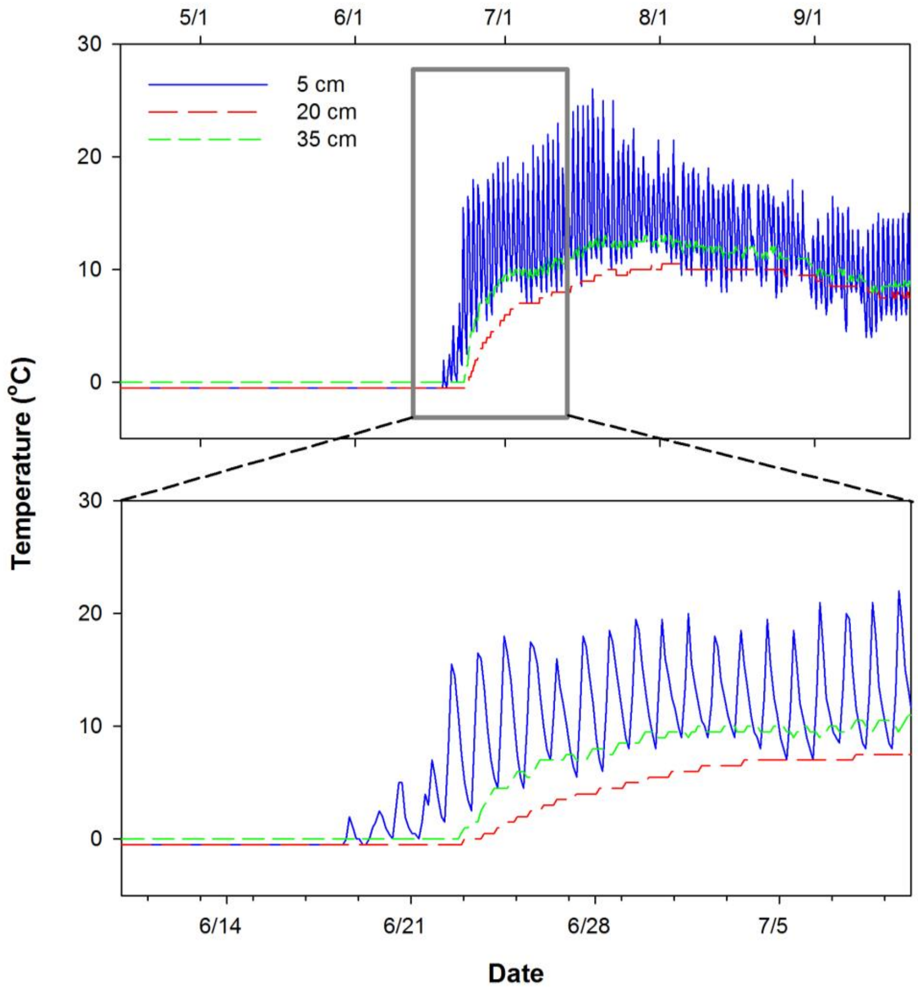


Figure 10. Representative temperature data from an array of temperature sensors located outside of the motorized track at the Buffalo Pass site.

Similar general patterns were observed at 35 cm depth. For peat soils located in non-motorized locations at the Buffalo Pass fen, temperatures for the three months preceding the start of melt-out ranged from -0.5°C to 1.5°C, not significantly different from those at motorized locations that ranged from -0.5°C to 1.5°C. In neither instance were differences statistically significant (t-test, p> 0.1). At the Rabbit Ears Pass fens, wintertime minimum temperatures ranged from -1 to 1°C for non-motorized locations and -0.5°C to 1°C for motorized locations, and were not statistically different from one another (t-test, p >0.1). Mean temperatures for control points were equal or slightly higher than motorized points, but differences between mean values were less than 1°C in each of the three months preceding melt-out and were not statistically significant (t-test, p > 0.1). At a depth of 35 cm, mean July temperatures were significantly lower in motorized than in non-motorized locations at the Buffalo Pass site (t-test. P < 0.001) but not the Rabbit Ears Pass site (Figures 12 and 14).

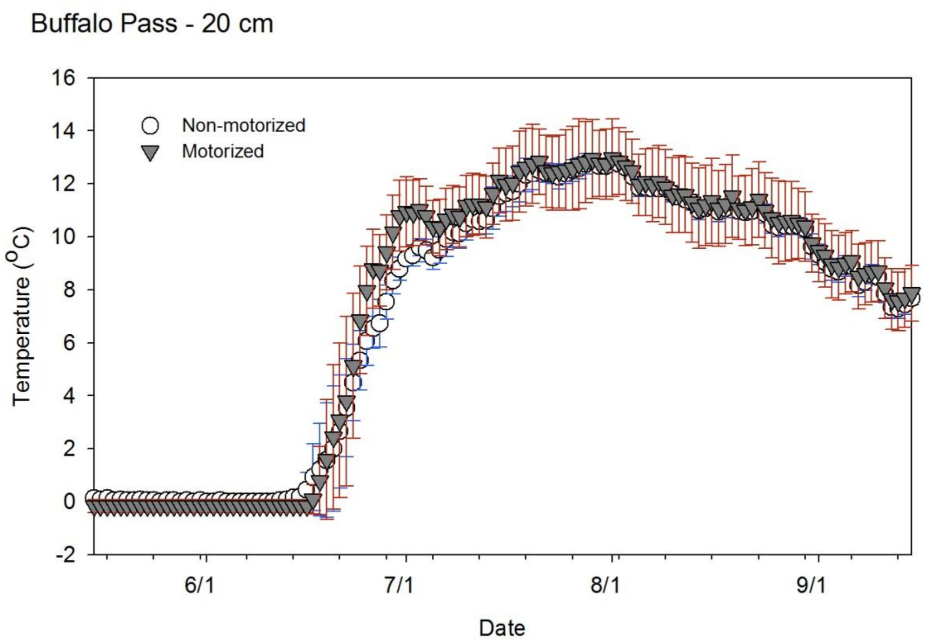


Figure 11. Mean soil temperature in 2010 (+/- 1 standard deviation) at a depth of 20 cm under motorized and non-motorized locations at the Buffalo Pass site (n = 10).

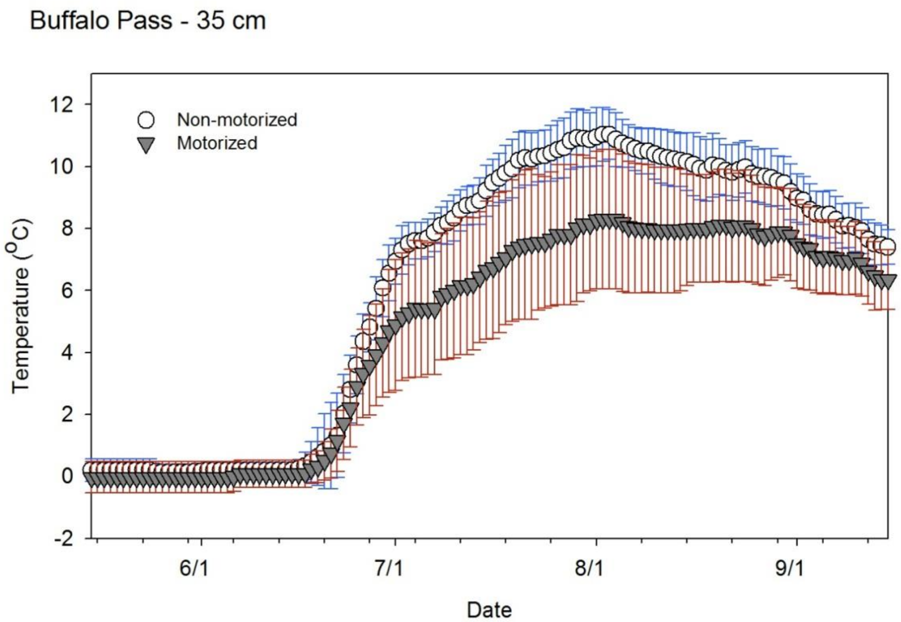


Figure 12. Mean soil temperatures in 2010 (+/- 1 standard deviation) for all sensors located at a depth of 35 cm under motorized and non-motorized locations at the Buffalo Pass site (n = 10).

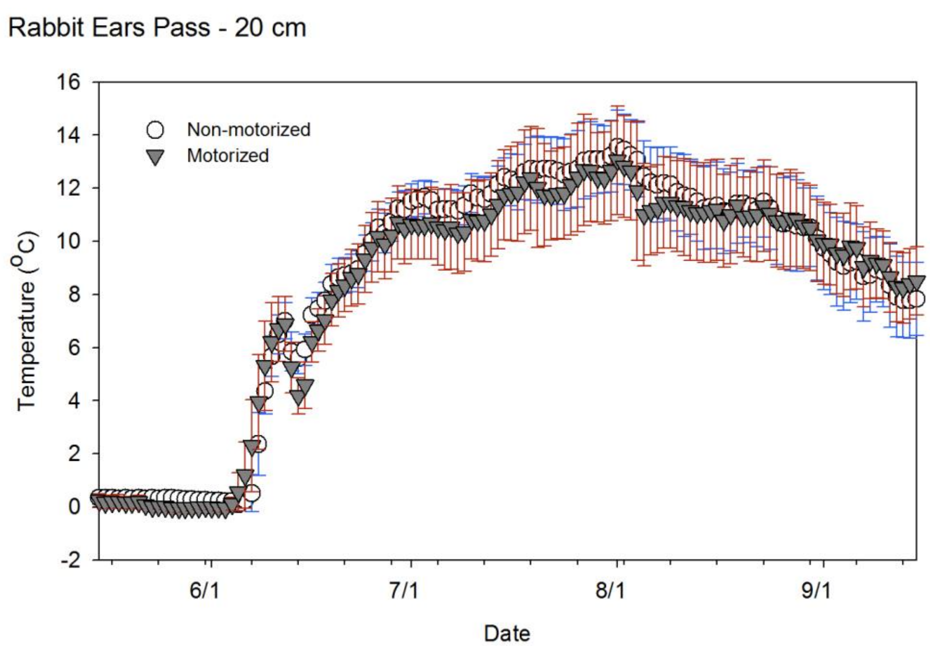


Figure 13. Mean soil temperatures in 2010 (+/- 1 standard deviation) for sensors located at a depth of 20 cm under motorized and non-motorized locations at the Rabbit Ears Pass site. Note that temperatures in the motorized locations drop slightly below 0°C.

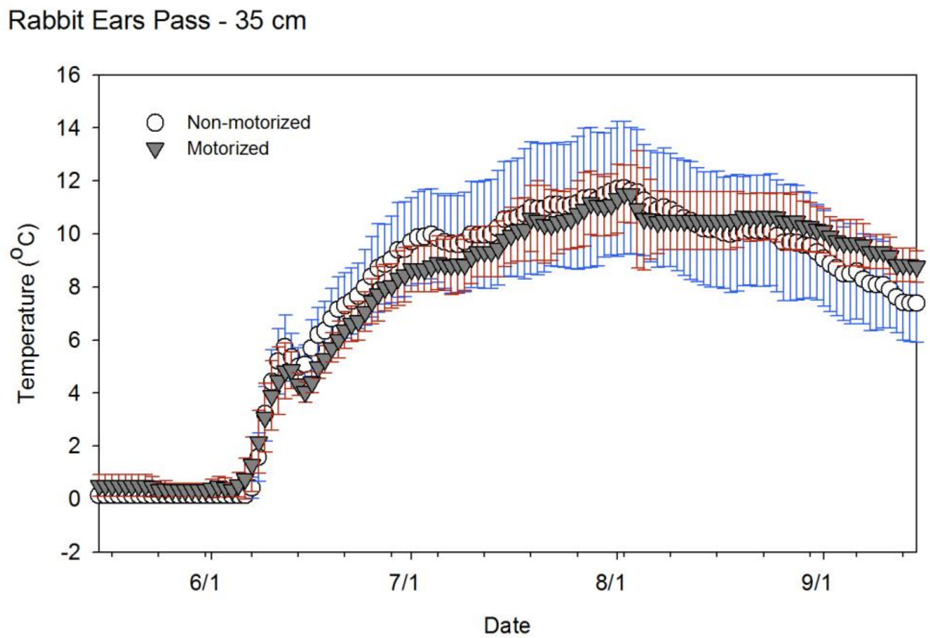


Figure 14. Mean soil temperatures in 2010 (+/- 1 standard deviation) for sensors located at a depth of 35 cm under motorized and non-motorized locations at the Rabbit Ears Pass site (n = 8).

The date of spring melt-out differed from year-to-year, but showed no statistically significant difference between control and compacted sites (t-test, $p > 0.1$). For example, the approximate date of melt-out in 2010 at the Buffalo Pass site was June 16 and was nearly identical for sensors located in motorized and non-motorized locations. In contrast, melt-out began approximately July 9 in 2011, but again, there was no statistically significant treatment effect. Because of an exceptionally dry spring in 2012, melt-out occurred approximately May 24 in soils in both control and compacted locations (Figures 16 and 17).

Monthly mean soil temperatures in control sites were generally higher than those in motorized locations at Buffalo Pass Fen, while the reverse was true at Rabbit Ears Pass sites. However, the magnitude of differences were small (less than 1°C—the precision of the sensor) and were not statistically significant for any month except August.

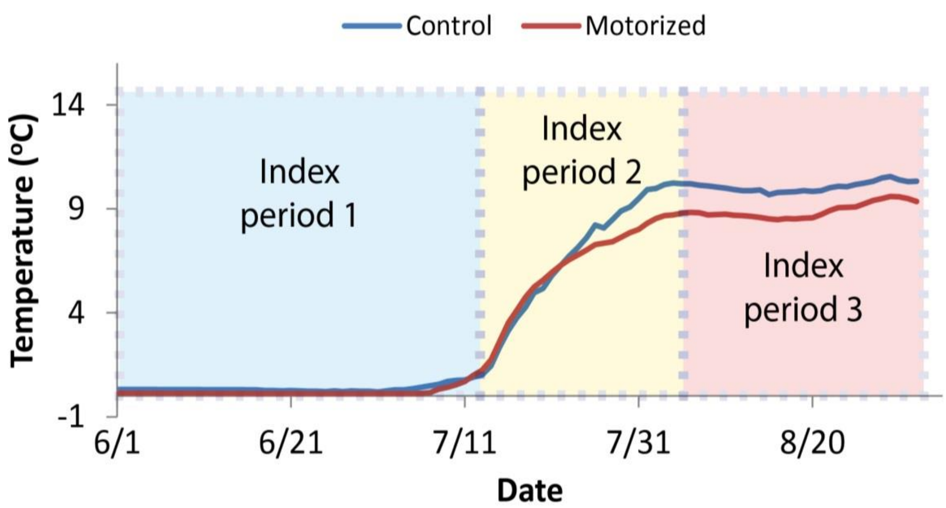


Figure 15. Mean 2011 soil temperatures at the Buffalo Pass Fen illustrating the three index periods used in statistical analysis. T-tests evaluating differences in mean temperature were not significant for any index period (IP1: p = 0.41; IP2: p = 0.86; IP3: p = 0.52)

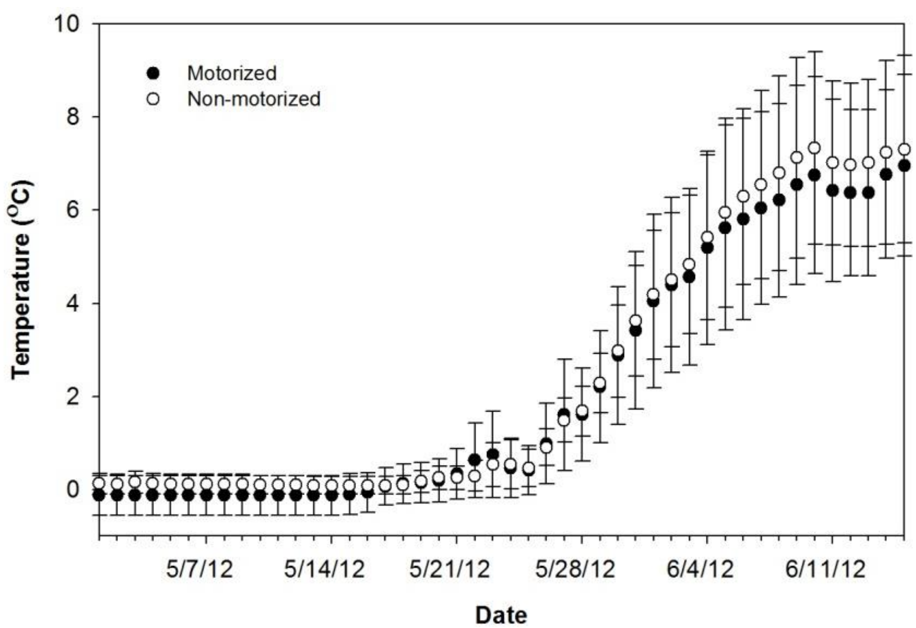


Figure 16. Mean daily soil temperature readings (+/- 1 standard deviation) from the Buffalo Pass site illustrating the spring melt-out.

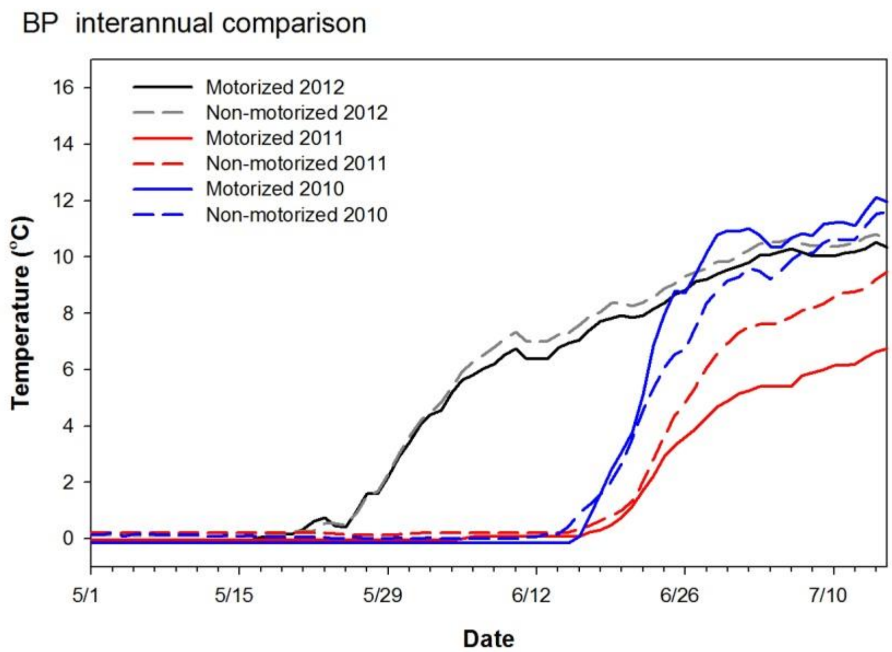


Figure 17. Mean daily soil temperatures from Buffalo Pass site for the 2009/2010, 2010/2011, and 2011/2012 seasons. Note the significantly earlier melt-out date evident in 2012.

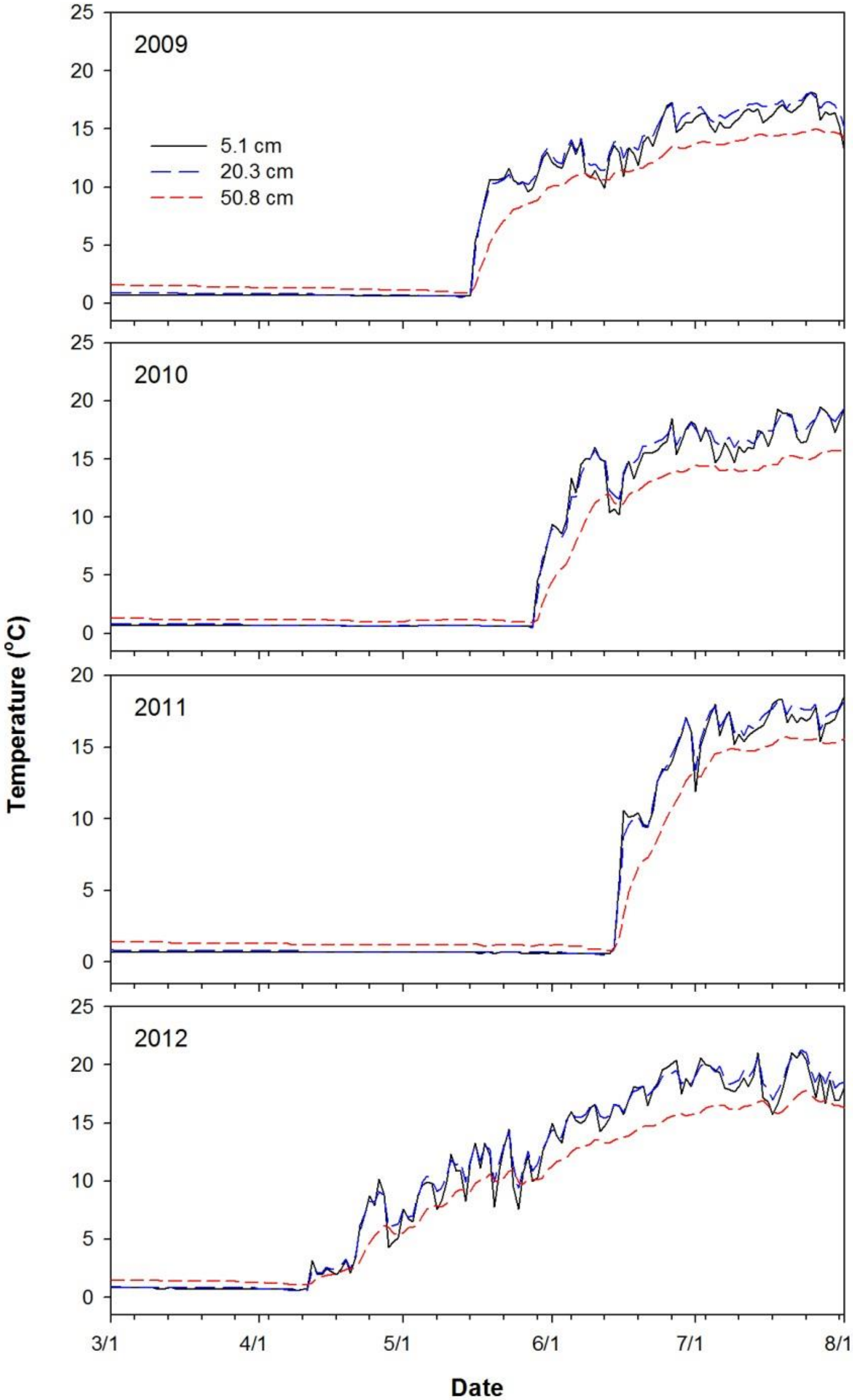


Figure 18. Dry Lake SNOTEL site soil temperature. Note that the SNOTEL site is located in a clearing in subalpine forest with mineral soils.

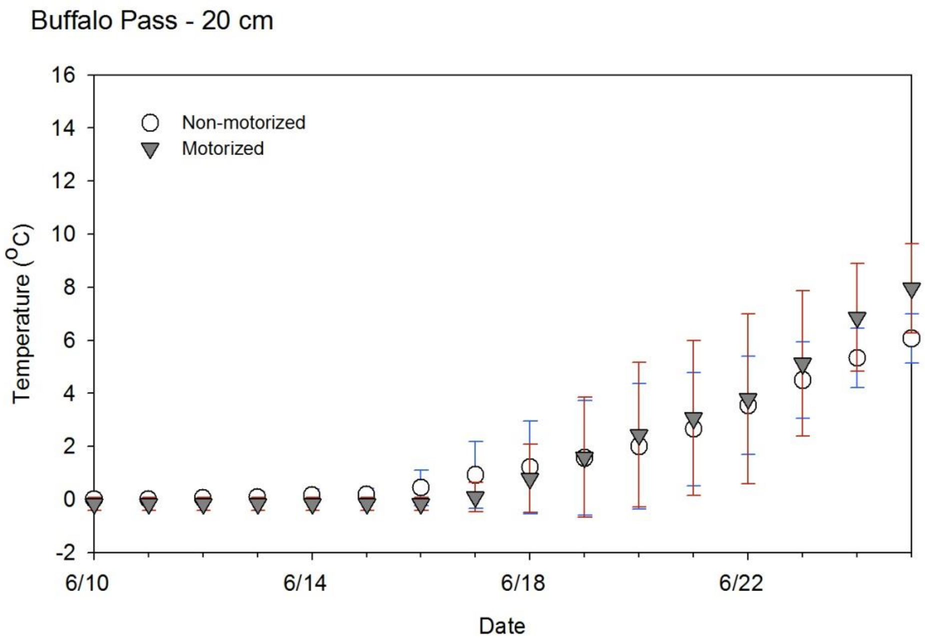


Figure 19. Mean soil temperature in 2010 (+/- 1 standard deviation) for sensors located at 20 cm depth under motorized and non-motorized locations. This figure highlights the late spring period during snowmelt.

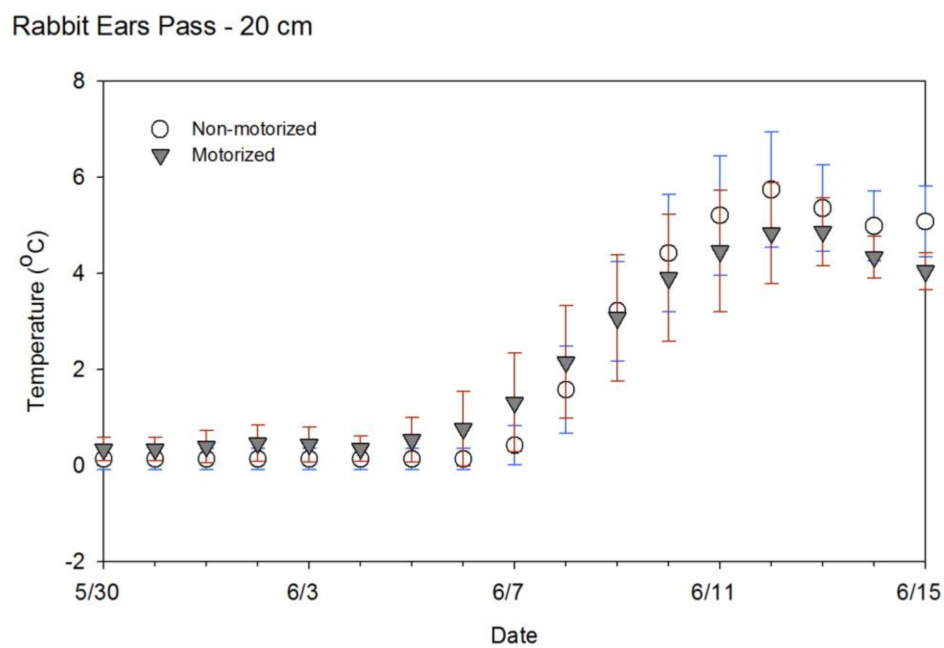
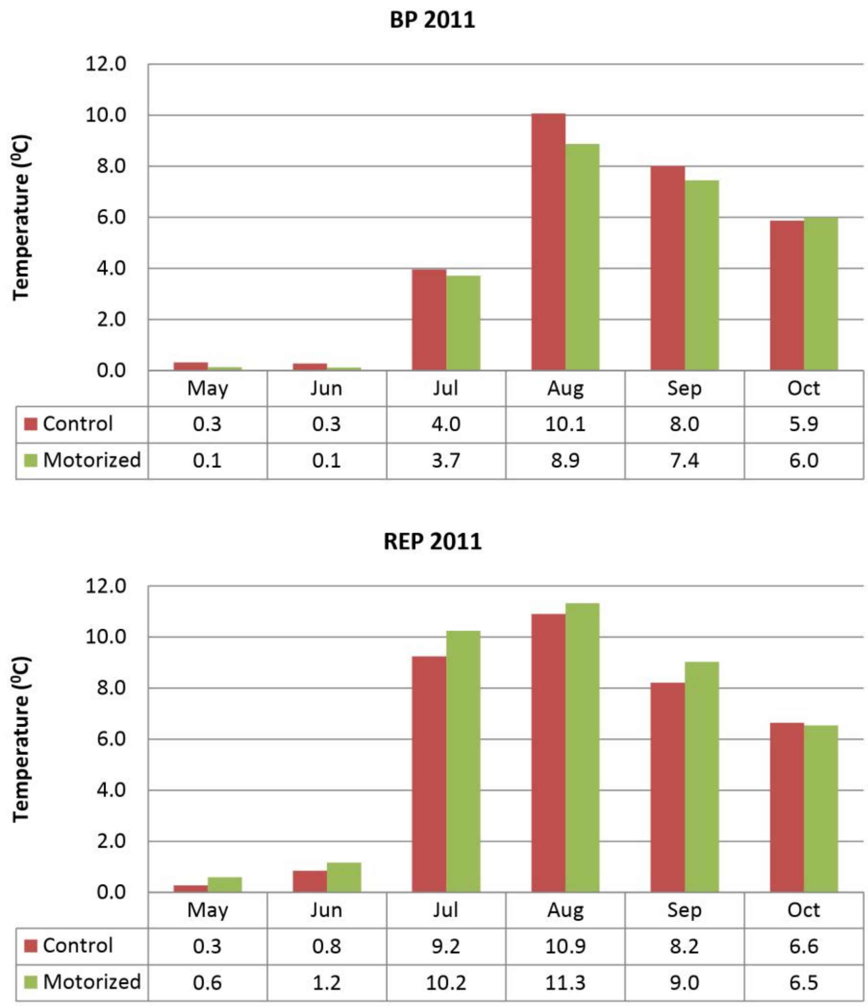


Figure 20. Mean soil temperatures in 2010 (+/- 1 standard deviation) for sensors located at a depth of 20 cm under motorized and non-motorized locations at the Rabbit Ears Pass fens. The plot highlights the late-spring period of snowmelt.



BP 2011

	May	Jun	Jul	Aug	Sep	Oct
Control	0.3	0.3	4.0	10.1	8.0	5.9
Motorized	0.1	0.1	3.7	8.9	7.4	6.0

REP 2011

	May	Jun	Jul	Aug	Sep	Oct
Control	0.3	0.8	9.2	10.9	8.2	6.6
Motorized	0.6	1.2	10.2	11.3	9.0	6.5

Figure 21. Monthly mean soil temperatures from the Buffalo Pass and Rabbit Ears Pass sites in 2011. Values represent monthly mean temperature (°C).

Soil temperature at the Dry Lake SNOTEL site (no soil temperature data are recorded at the Rabbit Ears Pass station) had a slightly different pattern than that observed in study area fens. In contrast to the peat soil temperatures we measured, soil temperatures near the ground surface (5 cm depth) were nearly identical to those recorded at a depth of 20 cm. Plots of seasonal soil temperature clearly illustrate the strong interannual variability in snowpack duration. At the Dry Lake SNOTEL site, for example, snow melted in early-April in 2012 while in 2011 it melted in mid-June (Figure 18). Notably, the SNOTEL sites are located in clearings in subalpine forest with mineral soils, and may be expected to show different thermal responses than in peat soils.

Dry Lake and Rabbit Ears Pass SNOTEL sites have considerable interannual variability in the date of melt-out . For the five year period ending in 2012, the range between the minimum and maximum melt-out date was 43 days and 51 days at the Dry Lake and Rabbit Ears Pass SNOTEL stations, respectively (Figure 16). The earliest melt-out date at the Rabbit Ears Pass site occurred on May 14, 2007, while the latest melt-out date occurred on June 26, 2011, with similar interannual patterns occuring at the Dry Lake SNOTEL site.

Winter soil temperatures in our experimental treatments at Rabbit Ears Pass were statistically indistinguishable from controls (ANOVA, $F = 0.02$, $p = 0.98$; Figure 22). Wintertime minimum temperatures were at or slightly above freezing for both controls and treatments. Melt out occurred in early May for the control and two treatments, but was slightly delayed in T2 plots compared to control and T1 plots. The treatment by date interaction term in the ANCOVA run on late spring/early summer period data was significant, indicating a difference in slope ($F = 46.68$, $P < 0.001$) among control and treatments. Evaluation of time series plots reveals that most of this effect is the result of differences in T2 plots. However, the ecological significance is likely small, as by early June, all plots shared a similar trajectory (Figure 22) and mean soil temperatures among treatments were not significantly different ($F = 0.48$, $p = 0.62$).

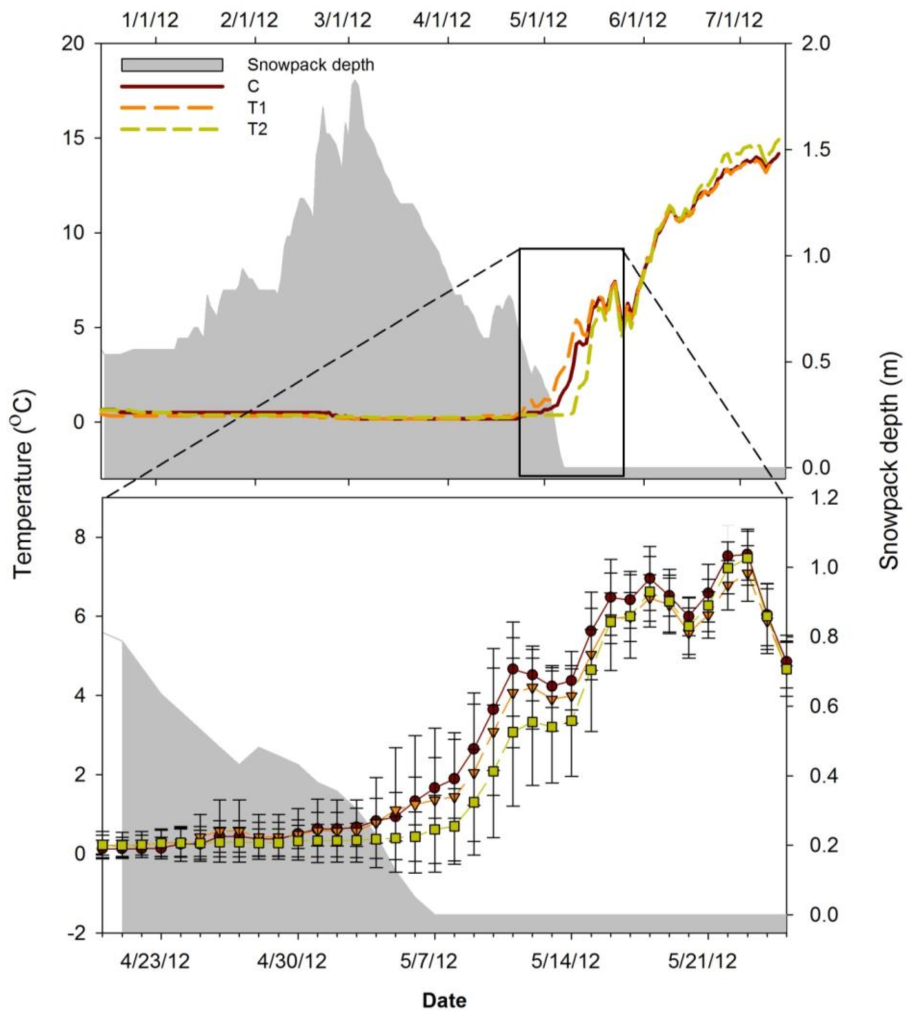


Figure 22. Mean (+/- 1 standard deviation) daily temperature readings from Rabbit Ears Pass experimental site in 2012 (depth = 20 cm). Treatment key: C = control (no compaction); T1 = treatment 1 (early-season compaction); T2 = treatment 2 (late-season compaction). Snowpack depth from the Rabbit Ears Pass SNOTEL site is provided for reference.

Production and decomposition

Aboveground standing biomass was highly variable among plots. For example, in 2010 biomass ranged from 87 g/m^2 to 408 g/m^2, a nearly 5-fold difference. The variability is attributed primarily to the dominant vegetation present. Plots dominated by larger-statured species (e.g., *Calamagrostis canadensis*, *Senecio triangularis*) produced more biomass per unit area than plots dominated by smaller species such as *Eleocharis palustris*. Mean biomass was higher in non-motorized plots at both sites in 2010, but these differences were not significantly different at either the Buffalo Pass ($t = 1.21$; $p = 0.273$) or Rabbit Ears Pass sites (t-test, $p=0.52$).

Mean biomass in clipping plots from the Rabbit Ears Pass experiment in 2012 was highest in the T1 treatment (mean = 151.6 g/m^2) followed by the T2 (mean = 103.4 g/m^2) and control plots (mean = 85.5 g/m^2) (Figure 23). However, variance was high and a one-way ANOVA indicated no significant treatment effects ($F = 2.18$; $P = 0.13$). As observed with clipping data from previous seasons, the high plot to plot variability primarily reflected vegetation composition differences, not the snow compaction treatment.

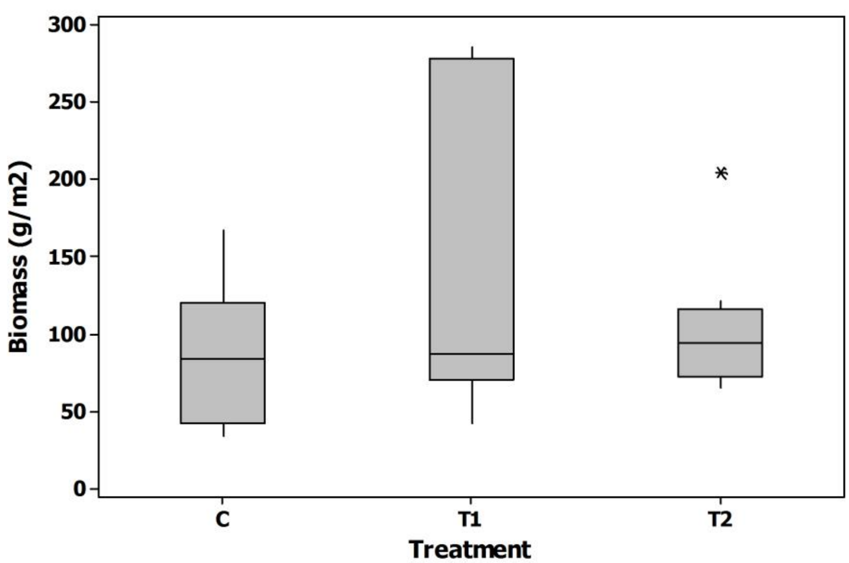


Figure 23. Boxplots of clipping biomass from Rabbit Ears Pass experimental plots. Differences are not statistically significant (ANOVA, P > 0.05).

The mass remaining (M_R) in litter bags declined over the study period, although mass loss was highly variable from location to location (Figure 24). After approximately 370 days at the Buffalo Pass fen, the mean M_R value was 0.43, but ranged from a minimum of 0.23 to a maximum of 0.62. After two years (743 days), mean M_R had declined to 0.29, but again varied widely from a minimum of 0.12 to a maximum of 0.41. Both subject and time since installation were significant in the repeated measures analysis of variance conducted on the Buffalo Pass data ($F = 9.24$, $p = 0.002$; $F = 31.98$, $p < 0.001$, respectively). However, treatment plots (motorized) compared to control plots was not statistically significant ($F = 0.14$, $P = 0.72$).

Decomposition patterns were more variable with the Rabbit Ears Pass data. The mean M_R after one season was 0.43, and ranged from 0.3 to 0.52. After two seasons, mean M_R had declined to 0.31, and ranged from 0.12 to 0.46. As with the Buffalo Pass data, time since installation was significant in the repeated measures analysis of variance ($F = 5.92$, $p = 0.045$), but treatment (motorized) when compared to the control plots was not statistically significant ($F = 0.54$, $P = 0.49$).

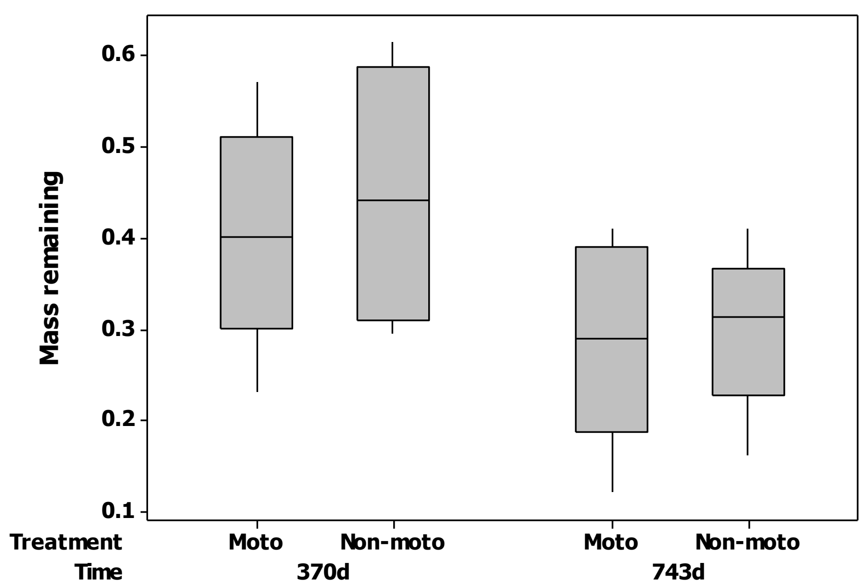


Figure 24. Mass remaining in litter bags after 370 and 743 days for bags in motorized and non-motorized plots in Buffalo Pass fen plots.

Remote sensing analysis

The statistical distribution of physiographic variables for points located inside and outside of the motorized use area overlap considerably. However, the distribution of points in the motorized zone was skewed to higher elevations. Most areas in the potential fen model have modest slope gradients, so aspect and elevation played a large role in defining cluster groups. The proportion of points supporting snow cover varied among clusters (Figure 25), and the "cluster" variable was highly significant (ANOVA, $F = 56.7$, $p < 0.001$), confirming the importance of physiography in influencing snowpack distribution patterns. Clusters 2, 3, 5 — those with points occurring at the highest end of the elevation gradient — had the greatest proportion of points scored as supporting snow across Landsat scenes.

While there were pronounced differences among clusters, only small differences in proportions within clusters were observed between points falling in motorized versus non-motorized areas. In addition, management status (motorized / non-motorized) was not a significant factor (ANOVA, $F = 0.18$; $p = 0.67$). Motorized areas had a slightly higher proportion of snow-covered points in three of six clusters. However, differences were small, and the reverse was true in the other three clusters (Figure 25). Two-sample tests for equality of proportions within clusters groups were only statistically significant in cluster 2 ($\chi^2 = 8.3$, $p = 0.004$).

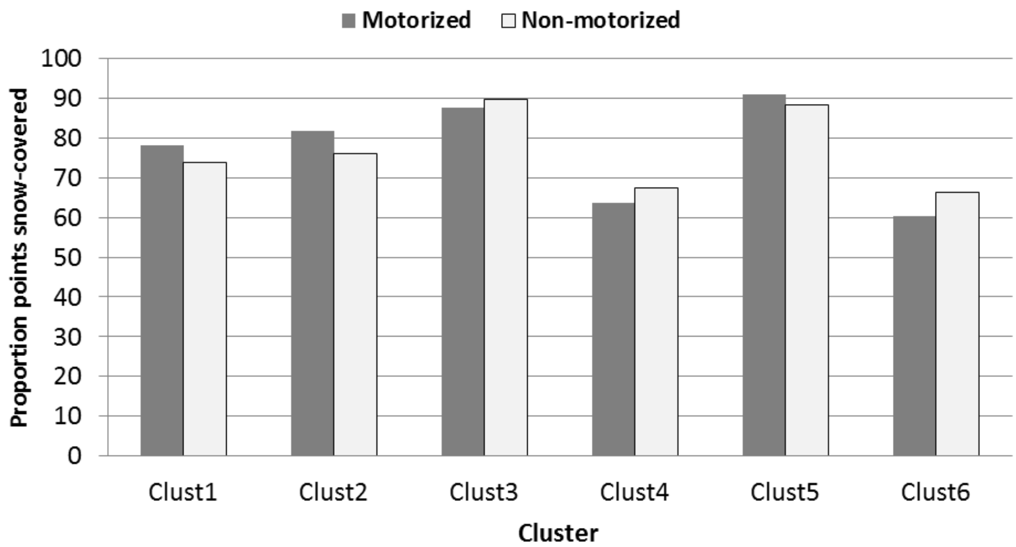


Figure 25. The average proportion of sampling points in each cluster group covered with snow on a given Landsat scene.

Prospect Basin

The most pronounced effect of mechanized grooming on the Prospect Basin fens was the freezing of soils, resulting in a significant delay in the melting of groomed areas. In 2009, soil temperatures started their summer increase in the non-groomed track on May 20 at Cottongrass Fen, while in the groomed track it began a full month later (Figures 26 and 27). Soil temperatures near the ground surface remained several degrees below those of non-groomed sites at Cottongrass Fen, although no such differences were observed at greater soil depth or in the Sven Fen site. In Sven fen a nearly 18 day difference was observed between the groomed and non-groomed areas (Figures 28 and 29).

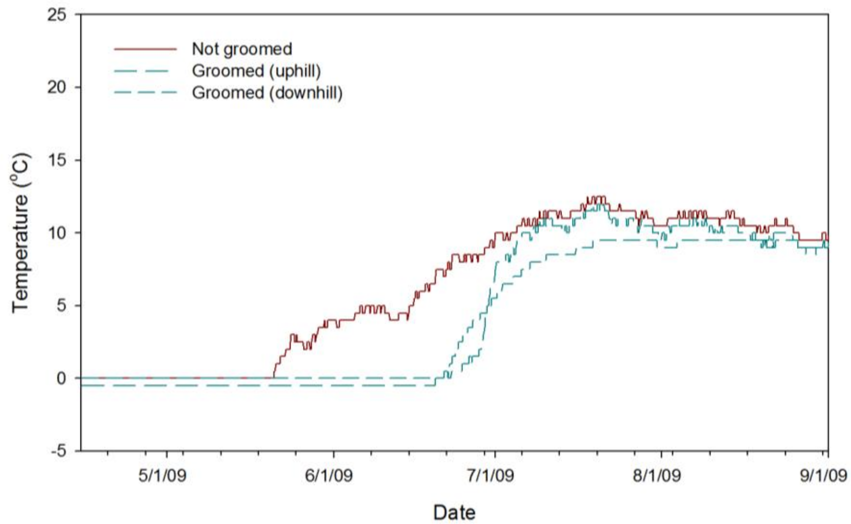


Figure 26. Peat temperatures at Cottongrass Fen, near Telluride, CO, at 20 cm depth.

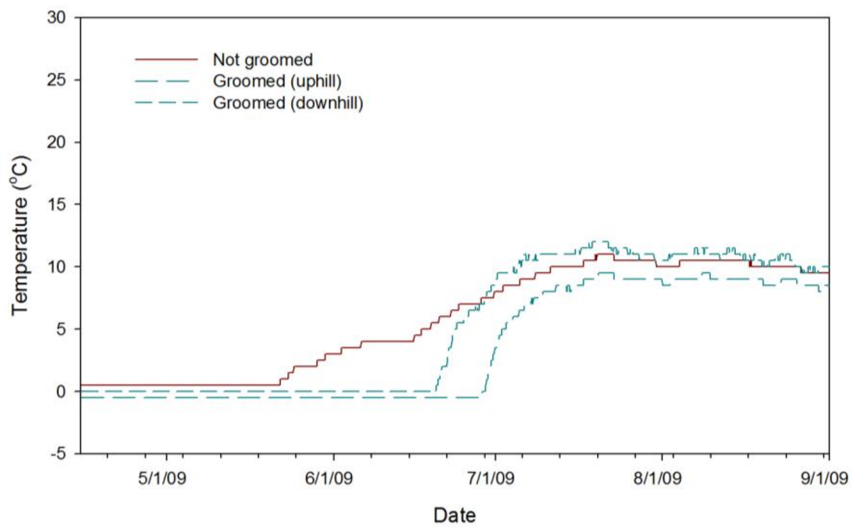


Figure 27. Peat temperature data from Cottongrass Fen, near Telluride, CO, at 40 cm depth.

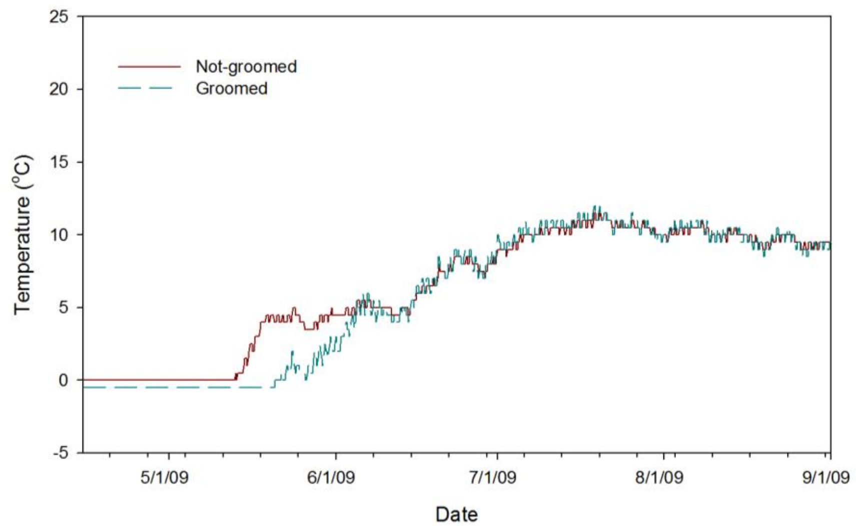


Figure 28. Peat temperature data from Sven Fen, near Telluride, CO, at 20 cm depth.

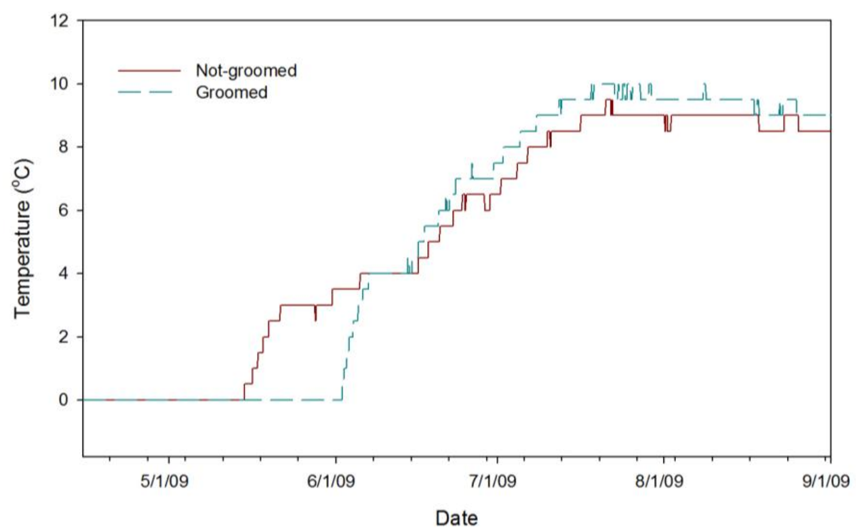


Figure 29. Peat temperature data from Sven Fen, near Telluride, CO, at 40 cm depth.

Discussion

Potential impacts to fens from winter recreation can be classified as direct or indirect depending on the mode of action. Direct effects include mechanical injury to plants or peat erosion and occur primarily when use occurs on a thin or discontinuous snowpack. These conditions occur in early and late season when user visitation rates are typically lower. We observed no direct impacts attributable to snowmobiles in our study fens.

Indirect effects are mediated through changes in snowpack thermal and peat soil properties. Potential indirect effects include changes in vegetation and ecosystem processes such as production and decomposition, which are sensitive to soil temperature and growing season length (Halfpenny and Ozanne 1989, Walker et al. 1993). Because of the indirect nature of their effects and high natural variability in natural ecosystem processes, it can be challenging to conclusively link stressors to ecological responses.

The effects of snow compaction on soil temperatures in the Rabbit Ears Pass experiment were not statistically different from the control plots, and time series plots do not suggest differences of obvious ecological importance. The same is generally true of contrasts between motorized and non-motorized points at the Buffalo Pass fen. More sensors in the motorized plots reached freezing temperatures, a biologically important temperature threshold. However, temperature differences did not affect melt-out date, and the control and treatment plots had nearly identical trends in soil warming in all sites.

This is in sharp contrast to Prospect Basin fens where pronounced differences in soil temperature persisted for many weeks into the summer months (Figures 26-29). Differences between sites in the date of melt-out were particularly strikingly. Melt-out and temperature rise at Cottongrass Fen occurred more than a month later in groomed sites than non-groomed controls. No such delay was observed in our Buffalo Pass and Rabbit Ears Pass study sites, where we observed similar melt-out dates in motorized and non-motorized areas.

Differences in soil temperature responses between the Prospect Basin and Routt NF fens are likely the result of two primary factors: the greater snowpack depth characteristic of the Routt NF sites and the intense nature of the compaction associated with mechanical grooming in the Prospect Basin fens. The Park Range is one of the snowiest areas in Colorado, likely buffering the more extreme effects observed at the Prospect Basin site. Snowpack depth is important because the amount of compaction typically is attenuated with increasing snowpack thickness (Halfpenny and Ozanne 1989). Also important, the frequency and intensity of compaction events was far greater at the Prospect Basin sites. This area received daily grooming in contrast to the monthly revisits in our Rabbit Ears Pass experiments. While the Buffalo Pass site generally saw daily use, snowcats used on the Routt are smaller than equipment used in Telluride, and in contrast to the latter, do not use tillers. Differences in local terrain and recreational use characteristics between sites are additional factors likely contributing to different soil temperature responses at Buffalo Pass and Telluride. The Telluride fens are in toe-slope locations at the bottom of steeper ski runs often seeing hundreds of runs per day.

While the difference in wintertime minimum soil temperatures was quite small between areas subject to motorized and non-motorized use, freezing temperatures (i.e., temperatures at or below 0°C) were observed with greater frequency in areas with snowmobile use. However, we observed no evidence of persistent frozen soils in field visits following snowpack disappearance in compacted areas at either the Buffalo Pass or Rabbit Ears Pass sites, and the timing of soil warming was almost identical between sites with and without snow compaction.

Effects from snow compaction documented for mineral soils, for example increased frost penetration (Ryerson et al. 1977, Rixen et al. 2003), can be ameliorated by the hydrologic conditions in fens. All of our study areas had water tables within 30 cm of the soil surface in mid-summer, and water tables are generally highest in winter and spring. A continuous influx of groundwater may limit freezing and maintain more constant soil thermal conditions.

The induction of soil freezing and changes in snowpack persistence and melt-out can influence vegetation composition and site carbon dynamics (Billings and Bliss 1959, Aurela et al. 2004). Examples from Prospect Basin and other regions suggest that mechanized grooming on the scale practiced in alpine ski areas can significantly delay spring snowmelt and soil warming for upwards of 4 weeks (Cooper and Arp 2002, Keller et al. 2004). However, such pronounced differences did not occur in any of the Routt NF study sites. While our temperature data revealed variability in soil thermal regimes, variation in factors such as groundwater depth and microtopography may limit the effects of compaction.

The ecological response variables we examined were centered on vegetation, and our results indicate no statistically or ecologically significant effects from snow compaction. We observed no consistent differences in mean biomass in motorized and non-motorized locations within fens. However, these sites were highly variable, attributable largely to fine-scale variation in factors such as species composition and water table depth rather than impacts from winter recreation. The importance of water table is highlighted in results from Prospect Basin suggesting that aboveground productivity may increase during dry years, but may be offset by increased decomposition (Cooper and Arp 2002).

Decomposition rates from control litter bags were also highly variable, but showed no consistent treatment effect from snow compaction. Litter decomposition is a complex process mediated by a diverse range of physical and biological factors including litter and water quality, soil fauna, and temperature (Thormann et al. 2001, Bradford et al. 2002). Given the absence of clear treatment effects on soil temperature, the lack of significant differences in decomposition between motorized and control plots are unsurprising.

We found no evidence of differences in plant phenology between motorized and control locations. Plot-to-plot variation in species composition limited our options for formal statistical analysis. Observational transects in motorized and control areas at the Buffalo Pass fen aimed at assessing phenological status of high visibility species (*Caltha leptosepala* and *Pedicularis groelandica*) did not indicate snow compaction effects. No indications of obvious phenological differences were seen in analyses of still and time lapse photographs, although high variability and the limited field of view and resolution of images prevented anything but a qualitative evaluation of photographs.

The distinct delay in plant development observed in groomed portions of Prospect Basin fens was not seen in either the Rabbit Ears Pass experiment or the Buffalo Pass site, even after several winters of directed snowmobile use and other compaction activities. Long-term impacts to species composition are possible due to subtle shifts in species interactions and competition, for example, to differences among species in thermally sensitive seed germination requirements (Fernández-Pascual et al. 2013), but such changes are without long-term monitoring.

Weather patterns varied tremendously during the study period, with extreme wet (2011) and dry (2012) snow years. Such variability has obvious implications for ecological and hydrological processes. For example, the length of the growing season, which for most herbaceous species is effectively the snow free period, has direct effects on annual productivity and plant phenology (Walker et al. 1995, Price and Waser 1998). The high interannual variability in the amount and characteristics of mountain snowpack dwarfs any anthropogenic effects from snow compaction, except in areas receiving early, frequent, and intense use like the groomed runs at Prospect Basin.

Properties including density, snow water equivalent, snow grain size and shape, and pore distribution all influence heat transfer through snow and evolve seasonally (DeWalle and Rango 2008). By altering some or all of these properties by snow compaction, winter recreation activities can affect snow's insulative properties (Heath 2011). A critical question is whether such impacts are ecologically significant. The answer may vary based on the specific resource in question (e.g., subnivean space for small mammals, peat accumulation/decomposition processes), and the spatial and temporal scale.

Snow compaction effects on subnivean space can affect small mammals and has received considerable attention from researchers (Courtin et al. 1991, Aitchison 2001, Sanecki et al. 2006). A snow depth of 20 cm was identified an approximate threshold for developing insulative properties (Pruitt 1970), although many snow characteristics (e.g., grain characteristics, density, etc.) are also important to insulation (Aitchison 2001). In his analysis of snowmobile compaction effects on subnivean space, Heath (2011) found significant compaction effects on snowpack and subnivean density in experimental snow courses subject to varying levels of compaction and starting on either a shallow or deep snowpack (30 cm and 120 cm). Differences with controls were statistically significant on early and mid-winter sampling dates for several measures of snowpack properties such as bulk density, snow water equivalent, and hardness, but differences generally declined as snowpack density increased in control sites through the spring (Heath 2011). The minimum basal snowpack layer temperatures in control, low and heavy use sites was -3°C, -3°C, and -2°C, respectably, in mid-December, but basal temperatures at all sites converged at -1°C by mid-April (Heath 2011). These results highlight the importance of initial snowpack conditions and suggest that any management aimed at ameliorating effects on subnivean space are best targeted towards early and late-season use.

After controlling for differences in physiographic setting through our cluster analysis, our remote sensing analysis of snowpack persistence identified no differences between motorized and non-motorized areas. If any impacts to snowpack duration occur, they appear to be minor and obscured by high background variability in snow distribution patterns. There are limitations to this approach. First, the resolution of the DEM is relatively coarse, limiting the precision of derived elevation products and the ability to capture fine scale variability in topography. In addition, we did not measure shrub and tree cover, which modify the local energy balance by absorbing incoming shortwave radiation and emitting long wave energy, affecting snow accumulation and ablation processes (Pomeroy et al. 2009).

Terrain characteristics such as slope steepness and aspect control snow accumulation and ablation (Schmidt 2010) and influence micro-environmental characteristics important in affecting snowpack morphogenesis throughout the winter and during melt-out. These same physiographic factors, at fine and coarse spatial scales, broadly shape the distributional pattern and functional characteristics of ecosystems. Fine-scale variation in physiographic characteristics may condition ecological responses to snow compaction. For example, subtle differences in aspect between the experimental Rabbit Ears Pass sites likely contributed to observed temperature variability in individual locations. Differences in slope and aspect appear responsible, in part, for the differences in seasonal soil thermal response among the Prospect Basin fens.

Like natural disturbances such as fire, anthropogenic disturbances can be described in terms of intensity, frequency, and extent. Mechanized grooming associated with Alpine skiing operations is both intense and frequent, but on an aerial basis, the extent of impact is typically smaller than that possible with snowmobiling. However, our failure to document significant changes in areas subject to high snow machine use such as Rabbit Ears Pass suggest that more remote areas are unlikely to show greater impacts.

Research within and outside the Southern Rockies clearly demonstrates that snow compaction from snowmobiles can significantly alter snowpack properties (Ryerson et al. 1977, Keddy et al. 1979, Stangl 1999). One study, for example, documented a 58% increase in density due to snowmobiling (Pesant 1987). Similar effects from snow machines have been observed elsewhere, including in Colorado (Cooper and Arp 2002, Heath 2011). Our experiment near Rabbit Ears Pass also documented obvious compaction. However, changes to snowpack in these plots and at our other sites did not produce significant changes in soil temperatures, the key driver of hypothesized ecological effects to fens.

Conclusions

- ***Our data and analyses indicate found no significant impacts to fens from winter recreation activities in the areas we investigated on the Routt NF.*** The mechanism driving hypothesized impacts to the ecological response variables examined in this study—changes in peat soil temperatures that result in freezing and delayed spring thawing—were not observed, and based on common measures of wetland condition, the Routt NF fens examined were in good condition.

- ***Compaction effects on fen soil temperature differ depending on mode and intensity of use.*** In contrast to data from other regions where mechanized grooming associated with Alpine skiing occurs (Fahey and Wardle 1998, Fahey et al. 1999, Cooper and Arp 2002), peat temperature data from motorized recreation areas on the Routt NF had no significant or consistent difference from control areas. Reports of strong reductions in soil temperature and deep frost penetration (Fahey et al. 1999) were not observed in either the Buffalo Pass or Rabbit Ears Pass sites. Prospect Basin soils did show clear changes in peat soil temperatures and a reduction in effective growing season length. In contrast, none of the study sites on Buffalo or Rabbit Ears Pass showed these effects.

The considerable variability in ecological response measures examined here is attributable in part to fine-scale variability in plant community composition, hydrologic regime, and physiography. The intensity, frequency, and spatial pattern of snowmobiling use is variable across the landscape (Keinath and McCumber 2007). The proximity of a fen to parking and trailhead locations and more difficult to quantify terrain and land cover characteristics influence the probability of snow compaction. This results in a broad range of use characteristics that, when coupled with natural variability in ecological structure and function present in the study area, limits our ability to make general statements of impact.

Our results do not preclude the occurrence of localized negative impacts to fens from winter recreation activities under conditions departing from those assessed here. Measurable impacts are most likely to occur where use is especially frequent or intensive. Underlying areas are most vulnerable to impacts when use occurs on a thin or patchy snowpack (Heath 2011). All of our sites were dominated by relatively common fen species and our analyses were focused on general ecosystem processes rather than the specific habitat requirements of individual taxa. However, some Routt NF fens support regionally rare species (Gage and Cooper 2006). Based on the precautionary principle, these sites may deserve special management and increased monitoring to ensure population viability.

Imperfect information on fen distribution and basic ecological characteristics is a key challenge in managing fens. Potential habitat models and maps derived from aerial image analysis techniques are useful, but may be inaccurate since the definitional characteristic of fens—the presence of a sufficiently thick peat layer—is not always discernible without direct examination of soils. Any future monitoring of potential impacts to fens from stressors would benefit from an improved fen inventory quantifying the distribution and condition of fens, similar to efforts conducted elsewhere in the region (Austin 2008, Chimner et al. 2010).

It is also important to recognize other stressors potentially affecting fens, for example, hydrologic alterations, invasive species, and livestock grazing (Chimner et al. 2006, Austin 2008). A potential stressor like snow compaction-induced changes to peat soils may interact with other factors (e.g., ditching), conditioning ecosystem responses (Preston and Bedford 1988, Chimner et al. 2010). These cumulative effects are often what matters to managers, as these are manifest as resource conditions on the ground.

Peat accumulates slowly in the southern Rocky Mountains, on the order of 2 cm per century (Chimner et al. 2002). As a consequence, relatively small changes to basic ecological processes may have lasting effects by shifting the balance between carbon accumulation and loss. We found no evidence conclusively linking snowmobile compaction to impairment of fen function, but it remains a potential stressor operating on the landscape. Because the thermal effects of snow compaction on peat soils are influenced by snowpack characteristics, predicted changes in the amount and timing of snow with climate change may also be important (Pauli et al. 2013).

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Appendix 1. Table of site locations

Well ID	Trt	UTMX	UTMY	Site
1	motorized	360992.0	4472120.0	Rabbit Ears Pass
2	motorized	359757.9	4472167.0	Rabbit Ears Pass
3	nonmotorized	357188.3	4469271.7	Rabbit Ears Pass
4	nonmotorized	357503.0	4469904.6	Rabbit Ears Pass
401	nonmotorized	357778.8	4469673.9	Rabbit Ears Pass
402	nonmotorized	357238.0	4469754.7	Rabbit Ears Pass
403	nonmotorized	357212.4	4470072.7	Rabbit Ears Pass
404	nonmotorized	357611.7	4469812.6	Rabbit Ears Pass
405	motorized	358696.9	4471837.5	Rabbit Ears Pass
406	motorized	359754.8	4472207.7	Rabbit Ears Pass
407	motorized	360456.4	4472121.6	Rabbit Ears Pass
408	motorized	361028.8	4472125.7	Rabbit Ears Pass
5	motorized	352049.5	4486704.9	Buffalo Pass
6	nonmotorized	352074.2	4486688.1	Buffalo Pass
7	motorized	352050.2	4486762.7	Buffalo Pass
8	nonmotorized	352084.1	4486762.3	Buffalo Pass
9	motorized	352050.5	4486798.1	Buffalo Pass
10	nonmotorized	352021.0	4486789.3	Buffalo Pass
11	motorized	352046.4	4486741.3	Buffalo Pass
12	motorized	352047.9	4486688.9	Buffalo Pass
13	motorized	352037.9	4486672.0	Buffalo Pass
14	nonmotorized	352074.6	4486675.8	Buffalo Pass
15	nonmotorized	352072.9	4486660.5	Buffalo Pass
16	nonmotorized	352076.3	4486774.0	Buffalo Pass