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Monitoring Ecological Functions of Spooner Meadow to Inform Restoration Implementation

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INTRODUCTION

Montane Meadows

Montane meadows are high elevation wetlands that occur below tree line in montane and subalpine zones in mountain landscapes. They occur in topographic depressions where surface water, runoff, snowmelt, and precipitation accumulate to create seasonally wet soils and a shallow water table. Montane meadows are also highly valuable ecosystems that provide critical functions for watersheds in mountain regions. They improve water quality by filtering nutrients and sediments, moderate flooding, support high rates of primary productivity and carbon sequestration, provide valuable habitat for flora and fauna, and support high biodiversity.

However, in the Lake Tahoe Basin, montane meadows are also among the most vulnerable ecosystems due to long-term changes in environmental conditions and historical land uses that altered hydrology (Marsolais and Moore 2016). These changes disrupt hydrologic connectivity and patterns of water flow through meadows, which can compromise the composition, productivity, and phenology of meadow plants, habitat quality, and the capacity of meadows to store carbon and water, cycle nutrients, and improve the water quality of surface waters that flow to Lake Tahoe.

The purpose of this project was to investigate ecological functions and processes of Spooner Meadow, an understudied montane meadow on the Nevada side of the Lake Tahoe Basin impacted by historical disturbances, in order to provide baseline conditions that will inform upcoming restoration activities. The goals of this project are consistent with those of the TRPA Threshold Standards and Regional Plan (TRPA 2012).

Spooner Meadow

Description and Setting

Spooner Meadow is an approximately 0.25 km^2 montane meadow complex* with an approximate elevation range of 2,109-2,130 m (6,920-6,990 ft) above sea level, located in Spooner Lake and Backcountry State Park, in Douglas County, NV (Figure 1). It is in the Marlette Lake-Frontal Lake Tahoe watershed (USGS HUC-10 #1605010102) and is connected to Spooner Lake, a reservoir that used to form the eastern portion of the meadow. Outflow from the lake (fed by snowmelt and surrounding seeps) is controlled by Spooner Dam and flows into North Canyon Creek, which originates from Snow Valley Peak, near Marlette Lake, and flows through Spooner Meadow. From Spooner Meadow, North Canyon Creek flows through Slaughterhouse Canyon via the Slaughterhouse drainage basin into Lake Tahoe near Glenbrook, NV.

Typical climate conditions in the region include dry, sunny summers and snowy winters. Monthly temperatures average 3.6 °C (38.5 °F) in the winter and 26 °C (78 °F) in the summer. Peak precipitation occurs as snow during late fall/winter months (November-January) and peak flow in North Canyon Creek occurs during snow melt in spring/early summer months (April-June)

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*In this study, Spooner Meadow was not defined according to the formal wetland delineation. Rather, it is a 0.25 km^2 study area that overlaps with the delineated boundary of "Wetland 1" and includes some adjacent upland habitat, and excludes "Wetland 2" described in the formal delineation (Huffman & Carpenter, Inc. 2009).

(Huffman & Carpenter, Inc. 2009). The growing season in the Lake Tahoe Basin occurs June 18-September 19 (UCANR 2018).

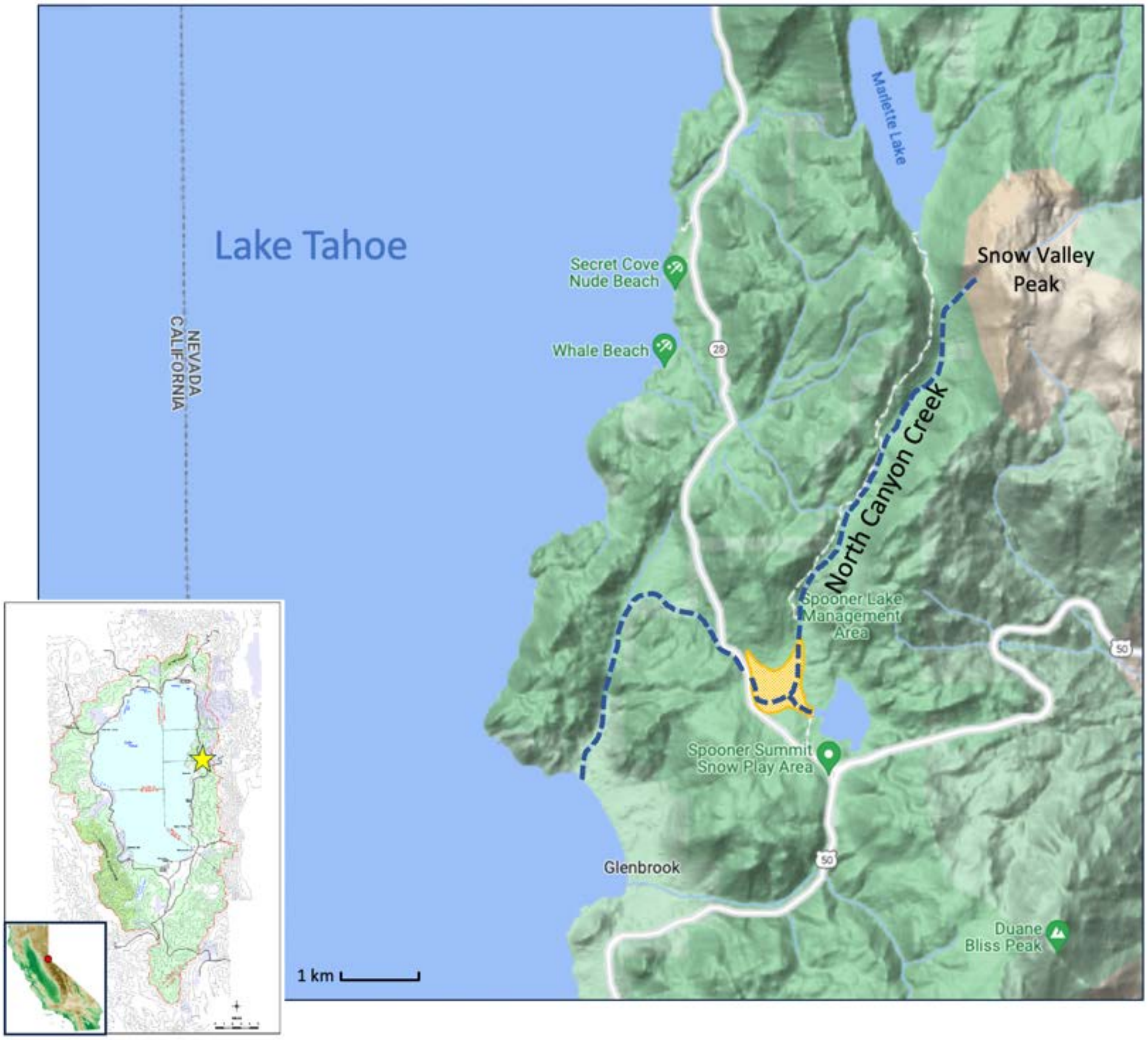

Figure 1. Location map of Spooner Meadow and North Canyon Creek.

History of Spooner Meadow

The Washoe tribe originally inhabited the Spooner area (encompassing the meadow, lake, summit, and surrounding area) and the broader Lake Tahoe region. Evidence of their historical presence can be found throughout the Spooner area, including grinding stones on the north side of Spooner Lake and several Washoe base camps that date back to 7,100 BP (Kimbrough 2025). Additionally, Spooner Meadow[†] served as a staging area for hunting and gathering during the summer months (Kimbraugh 2025).

[†]Please note: According to Kimbrough (2025), "Spooner Meadow" historically referred to a collection of meadows in the Spooner Summit-Marlette Lake region rather than the specific meadow that is the subject of this study. Historical land use and disturbances may not all apply specifically to what is considered Spooner Meadow in this study.

With the arrival of European settlers in the early 1800s, the Washoe population declined. Later, during the Comstock Era (1859-1880), Spooner Meadow, North Canyon Creek, and the surrounding area were heavily used for lumber, irrigation, and ranching. These activities substantially altered hydrology in North Canyon Creek and Spooner Meadow. In the 1860s, as described by Kimbraugh (2025), a dam was built in North Canyon Creek to create a mill pond in the eastern portion of Spooner Meadow. The pond was the original iteration of present-day Spooner Lake and supplied water to shingle and sawmills built in Spooner Meadow (subsequent dams converted the pond into present-day Spooner Lake). Ditches and dams were built in the meadow to divert surface water to the onsite sawmills. In 1870, a V-flume was built in North Canyon Creek that carried water from Marlette Lake to Spooner Summit for the Clear Creek Flume, which transported lumber to Carson City. By the early 1900s, Spooner Meadow was primarily used for ranching activities, particularly sheep and cattle grazing. Ranchers built structures on the meadow for ranching operations and irrigated the meadow to promote the growth of forage for livestock by constructing ditches and removing beaver dams.

Today, Spooner Meadow and the surrounding area are used for recreation (e.g., hiking, cross-country skiing and snowshoeing, fishing). A series of culverts direct flow from North Canyon Creek under North Canyon Road on the east side of the meadow (i.e., upstream of Spooner Meadow) and under Highway 28 on the west side (i.e., downstream of Spooner Meadow). The portion of North Canyon Creek that runs through Spooner Meadow is highly channelized. North Canyon Creek has been identified as a Category 5 impaired waterbody by the EPA (NDEP 2022). Historical disturbances to meadow and creek hydrology (e.g., ditches, diversions, dams) continue to alter natural surface flow and groundwater elevations, modifying the distribution of water across the meadow (Huffman & Carpenter, Inc. 2009).

Project Scope

This monitoring project collected data on vegetation, soil, and hydrology characteristics that drive ecological functions and processes of Spooner Meadow to inform overall meadow health. Data collected during this project will serve as important baseline data for upcoming restoration implementation. Data can be used to evaluate ecological performance criteria for restoring meadow health and historical hydrologic patterns.

We conducted a monitoring study of Spooner Meadow from April 2023 to June 2025, collecting field data on vegetation, soil, and hydrology characteristics that inform ecological functions and processes (namely habitat, biodiversity, productivity, decomposition, and ability of the meadow to improve water quality), and supplemented field data with remote sensing and local SNOTEL environmental data to evaluate current and long-term ecological trends.

Justification

While numerous studies have investigated montane meadows in the Lake Tahoe Basin, these studies generally focus on the more extensive meadow complexes on the California side of the Basin or are conducted at a regional scale, lacking fine-scale, meadow-specific data. Montane meadows on the east side of Lake Tahoe are largely overlooked in detailed research and monitoring efforts. To our knowledge, little research has been conducted at Spooner Meadow and site-specific data are scarce. Yet it is one of the biggest meadow complexes on the Nevada side of the Lake

Tahoe Basin and baseline data of existing ecological conditions can greatly benefit upcoming restoration work.

Project Goals and Objectives

The overall goal of this project was to assess baseline conditions of ecological functions and processes of an understudied montane meadow in order to inform restoration implementation, the development of condition assessment metrics, and long-term Spooner Meadow management actions. Our project objectives included:

- Monitoring vegetation, soil, and hydrology characteristics to evaluate productivity, habitat, biodiversity, and decomposition at Spooner Meadow under current conditions
- Evaluating long-term snowpack, temperature, and precipitation trends in the local area
- Evaluating long-term vegetation trends in Spooner Meadow, including plant production, vegetation health, and encroachment of woody vegetation
- Increasing our understanding of water quality conditions of North Canyon Creek, which flows through the meadow and into Lake Tahoe
- Engaging college students in hands-on scientific research by recruiting research assistants from UNR and TMCC to participate in field and lab work activities

STUDY DESIGN

This project uses a combination of environmental datasets, field data, and remote sensing to evaluate the ecological functions and processes of Spooner Meadow. Collectively, these data inform current baseline conditions ahead of planned restoration activities.

Environmental datasets

We compiled temperature, precipitation, and snowpack data from the Marlette Lake SNOTEL Monitoring Site (Site No. 615; managed by USDA National Resources Conservation Service, National Water and Climate Center) to evaluate long-term temperature, precipitation, and snowpack trends dating back to the 1970s and 1980s. We also compared SNOTEL soil moisture and temperature conditions to soil sensor data collected in Spooner Meadow.

Field Measurements

Field data were collected from July 2023 through June 2025 at Spooner Meadow. We collected soil and vegetation data from five 500 m^2 circular plots (Figure 2) and water quality data from North Canyon Creek.

Figure 2. Locations of Study Plots. Plots are shown as circles. North Canyon Creek and tributaries are shown as blue lines. (Note: not all tributaries are shown here; water features shown here are intended to provide general hydrologic context for the study plots and may not match formally delineated features.)

Plots were positioned at various distances from North Canyon Creek to capture conditions representative of the meadow (Table 1). The center of each plot was marked by a PVC post. Plots 1, 2, 4, and 5 were within the bounds of the formally delineated wet meadow, whereas Plot 3 was upslope in a drier area more characteristic of a mesic meadow (Huffman & Carpenter, Inc. 2009).

Table 1. Study plot locations, elevations, and distances to North Canyon Creek.

Plot	Latitude (dd)	Longitude (dd)	Elevation	Distance from creek (m)[a]
1	39.112168	119.921040	2,110 m (6,924’)	95
2	39.110052	119.921067	2,111 m (6,927’)	16
3	39.110058	119.918108	2,118 m (6,948’)	68
4	39.109328	119.916109	2116 m (6,943’)	0
5	39.111748	119.915968	2120 m (6,957’)	12

[a]Linear distance from plot center to main North Canyon Creek channel.

Meadow Soil Characteristics

We installed a wireless Onset HOBOnet Multi-depth Soil Moisture Sensor (RXW-GP3A-900) in the center of each plot that collected data at 15-minute intervals for the duration of the study.

Sensors measured volumetric water content (VWC) and temperature to a depth of 45 cm. Soil moisture (VWC) was measured at depths of 0-15 cm, 15-30 cm, and 30-45 cm. Soil temperature was measured at depths of 3.5, 10, 20, 30, 40, and 45 cm. Data from sensors were relayed to a data station installed near Plot 4. Sensor data were transmitted to an Onset data cloud (Hobolink) every hour.

Meadow Vegetation Characteristics

In each plot, we measured vegetation in five 1-m^2 quadrats to inform habitat, biodiversity, productivity, and decomposition functions and processes. To evaluate these characteristics, we collected data on plant species composition, phenology, aboveground biomass (AGBM), and decomposition rates. Quadrats were randomly positioned in each circular plot. New random quadrat locations were used each year. Each quadrat was divided into 0.25 m^2 quarters; different vegetation measurements were collected in each quarter (Figure 3).

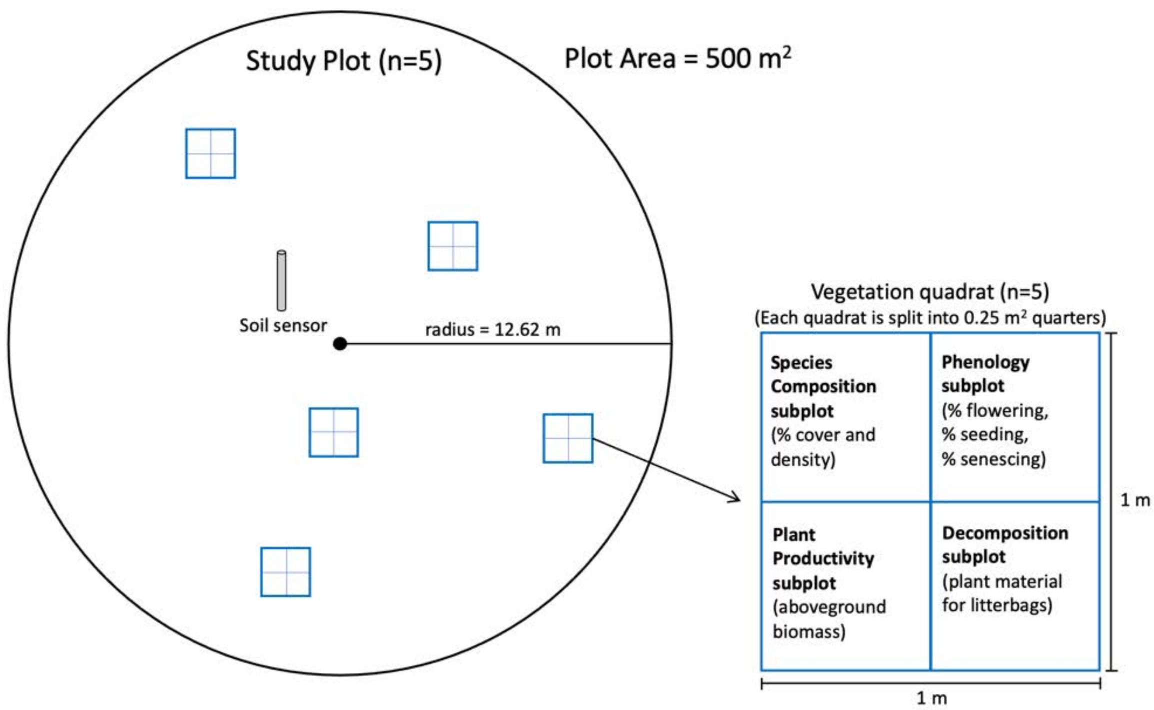

Figure 3. Study Plot diagram and vegetation sampling design. Not to scale.

In one quarter of the quadrat, we recorded absolute percent cover and density of each plant species. These measurements characterize the plant composition of the meadow, which informs habitat and biodiversity. Percent cover estimates included live species, bare ground, and thatch. Density was measured by counting the number of individuals of a given species within the subplot. Percent cover and density data were collected in August 2023 and July 2024.

In the second quarter, we recorded phenology characteristics (% flowering, % seeding, % senescence) of the dominant plant species during the 2023 and 2024 growing seasons. Phenology is a component of habitat and productivity that is influenced by snowpack, the timing of spring snowmelt, and annual precipitation and temperature patterns.

In the third quarter, we measured AGBM. Aboveground biomass is an estimate of annual aboveground primary productivity. We clipped all plant material to ground level during peak annual production (August 2023 and 2024). Plant material was dried to a constant mass and weighed. Measurements were converted to grams of biomass per square meter.

In the fourth quarter of the quadrat, we collected aboveground plant material for litterbags, which were deployed to measure rates of decomposition. Decomposition rates inform carbon accumulation and are influenced by temperature and precipitation. The litterbag study was repeated in Years 1 and 2. In 2023, plant material was collected in July 2023 and dried to a constant mass. Dried material was placed into litterbags made from window screen. Each litterbag was filled with 10 g of dry plant litter. In July 2023, five bags were deployed in each Study Plot (Round 1) and secured with fishing line attached to landscape stakes. One litter bag per plot was collected sporadically through August 2024, dried and weighed, then compared to the initial dry weight. In Year 2, a second round of plant material was collected, dried and deployed in litter bags (5 per plot) in August 2024 (Round 2). These bags were subsequently collected, dried, and weighed through June 2025.

Shrub and Tree Encroachment

In Fall 2023, four students from Truckee Meadows Community College collected data to investigate potential shrub encroachment into Spooner Meadow. The students participated through DRI's Research Immersion Internship Program to gain experience conducting hands-on research, learn about meadow ecology, and build professional and soft skills. The students characterized current shrub cover by collecting shrub density, percent cover, and seedling data along 8 transects that extended from adjacent uplands into the meadow. Four of the transects were 100 m long and four were 50 m long. They also used historical imagery to determine changes in woody vegetation into the meadow from 1969 to 2020.

A separate remote sensing analysis was done using the RAP Cover dataset (Table 2) to evaluate potential tree encroachment from 1986-2024.

North Canyon Creek Water Quality and Meadow Snowpack

In addition to soil and vegetation measurements, we measured water quality characteristics of North Canyon Creek and snowpack at Spooner Meadow. Water quality measurements were collected on a regular basis from December 2023 through June 2025. We measure dissolved oxygen (mg L^{-1}), percent dissolved oxygen, conductivity (($\mu S\ cm^{-1}$), specific conductance ($\mu S\ cm^{-1}$), total dissolved solids (mg L^{-1}), salinity (ppt), and temperature (°C) using a YSI handheld water quality meter at four locations along North Canyon Creek: 1) upstream of Spooner Meadow, 2) at the culvert where water flows into the meadow from Spooner Lake, 3) near the center of the meadow, and 4) downstream of the meadow (Figure 4). During winter months, we used a measuring stick to measure snow depths near the Study Plots and water quality sampling locations, as well as at random locations within the meadow.

Figure 4. Water quality sampling locations along North Canyon Creek.

All field work was carried out by the project PI and by undergraduate research assistants from UNR and TMCC.

Remote sensing

We used publicly available remote sensing data to evaluate Spooner Meadow vegetation characteristics over time. Initial investigations were conducted using Google Earth Engine. Refined analysis was conducted using Climate Engine, a cloud-based platform for spatial analysis created by DRI that leverages publicly available satellite imagery and derived products through Google Earth Engine (Huntington et al. 2017). Specifically, we evaluated measures of productivity, vegetation health, and encroaching tree cover during the period of 1986 to 2024 at Spooner Meadow.

Table 2. Remote sensing derived products used in temporal spatial analysis.

Dataset	Variable	Date Range	Spatial Resolution	Frequency	Statistic	Source
RAP[a] Production	Total herbaceous aboveground production (lbs acre^{-1})	1986-2024	30 m	Annual	Mean Values	USDA Agricultural Research Service
RAP NDVI[b]	NDVI	1986-2024	30 m	16-day	Mean Values	USDA Agricultural Research Service

RAP Cover	% Tree cover	1986-2024	30 m	Annual	Mean Values	USDA Agricultural Research Service

[a]Rangeland Analysis Program
[b]Normalized Difference Vegetation Index

PROJECT FINDINGS

Long-term Weather Trends

According to data records from the Marlette Lake SNOTEL Monitoring Site, maximum air temperature (peak summer temperature), which overlaps with the growing season, has remained similar between 1989 and 2024 (Figure 5). Average maximum air temperature during that time span was 27.5 °C (81.5 °F). During 2023, maximum air temperature was 27.7 °C (81.9 °F), and in 2024 it was 29.5 °C (85.1 °F). This study concluded in June 2025, before peak summer temperatures occurred. For that reason, 2025 temperature data were not included in long-term temperature analysis.

Total annual precipitation averaged 85 cm between 1989 and 2025, but fluctuated considerably between years (Figure 5). The highest amounts of precipitation occurred in recent years (166 cm in 2017 and 145 cm in 2023). Precipitation dropped in 2024 and 2025, but remained higher than drought periods in the region (1987-1992, 2007-2009, 2011-2015).

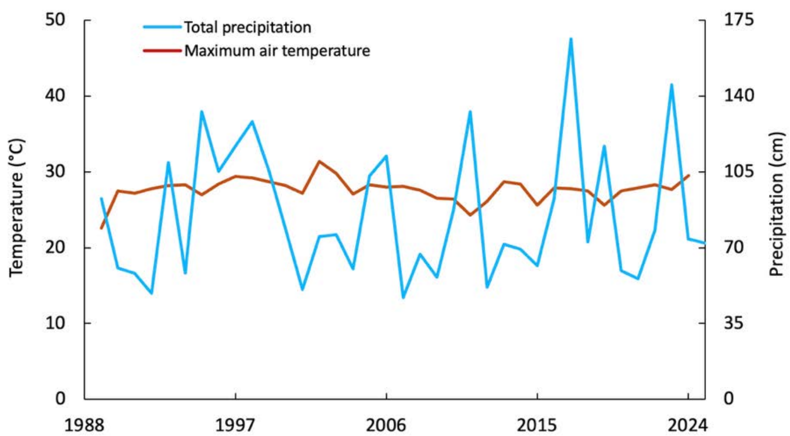

Figure 5. Maximum air temperature and total annual precipitation recorded at the Marlette Lake SNOTEL Monitoring Site (1989-2025).

Snow water equivalent (SWE) is the amount of liquid water stored in snowpack (i.e., the amount of water there would be if the snow melted). It is used to determine how much water there is in the snowpack that will contribute to runoff and water recharge during snowmelt. At the Marlette Lake SNOTEL Monitoring Site, SWE averaged 66 cm from 1979 to 2025 but fluctuated greatly between years (Figure 6). During this time span, SWE was highest in 1983 (148 cm). The second highest SWE occurred in 2023 (136 cm), just before this study began. The SWE in 2024 and 2025 was slightly below average (62 cm in both years).

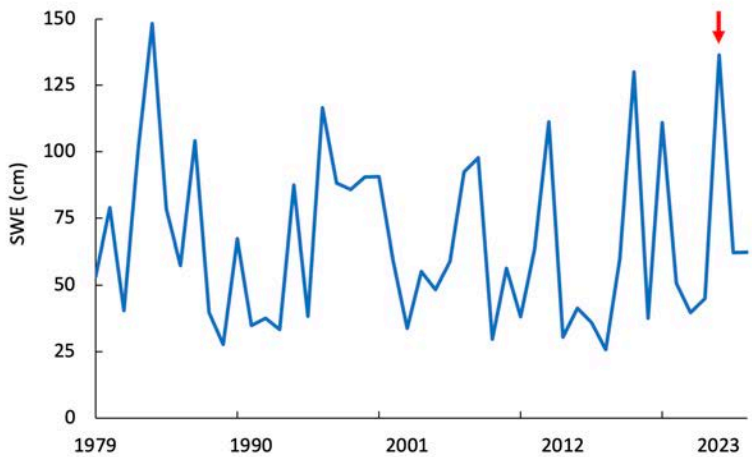

Figure 6. Maximum annual snow water equivalent (SWE) recorded at the Marlette Lake SNOTEL Monitoring Site (1979-2015). Red arrow points to record snow year in 2023 that occurred the year this study began.

Soil Characteristics

Characteristics like soil moisture and temperature can be useful indicators of meadow health and inform vegetation trends and hydrologic connectivity or seasonal water flow through the meadow. Soil moisture and temperature can also inform the primary ecological function of carbon storage. Meadow soils are hydric soils, meaning they are saturated or flooded long enough during the growing season to create anaerobic conditions. In hydric soils, decomposition occurs slowly and organic matter (e.g., dead plant material) builds up, causing meadows to be carbon sinks (i.e., store carbon in live vegetation and in slowly decomposing organic matter that builds up in the soil).

Most of the Spooner Meadow study site has a soil type known as Tahoe complex, 0 to 2 percent slopes, which is a poorly drained, moderately permeable hydric soil (7041) (USDA 2007). Plots 1, 2, 4, and 5 occur within this soil type. Plot 3 occurs within the Cagwin-Rock outcrop complex, 5-15 percent slopes, extremely stony (7411) (USDA 2007). This is a non-hydric soil that is somewhat excessively drained and has moderate permeability that typically supports forest and shrub communities.

Soil Moisture

During soil monitoring (July 2023 to June 2025), soil moisture fluctuated seasonally (Figure 7). This was most notable at Plots 1 and 2. Soil moisture, measured as the volumetric water content (VWC; volume of water per volume of soil), was typically between 0 and 25% in Plots 1 and 2[‡] during summer and fall months. Soil moisture increased during winter and peaked during spring, reaching approximately 65%. In Plot 3, located upslope in mesic meadow habitat, VWC was typically lower than at the other plots, and less influenced by seasonal hydrology. At Plots 4 and 5[§], VWC was also less seasonally pronounced and generally hovered around 40-65%. These areas

[‡] The soil sensors in Plots 1 and 2 stopped working in March 2025; the cables connected to the sensors appeared damaged and could not be repaired, hence soil data for these plots runs from July 2023 to March 2025.

[§] The soil sensor in Plot 5 was damaged by a snowstorm in January 2024 and replaced in June 2024, hence the data gap in Figures 7 and 8.

of the meadow were consistently saturated or flooded during fieldwork and close to several North Canyon Creek tributaries. The nearby waters likely moderated seasonal fluctuations by supplying surface water much of the year. These two plots were generally flooded or saturated when not covered by snow. Values of VWC varied across soil depths, though they followed similar patterns. Soil moisture nearest the surface (0-15 cm) typically fluctuated more than soil moisture at lower depths, suggesting this depth range was most influenced by precipitation, surface inundation, and water update by meadow plants.

To better understand soil moisture and temperature at Spooner Meadow relative to the broader surrounding area, we also evaluated soil data from the Marlette Lake SNOTEL Monitoring Site (#615). The SNOTEL site is not in a meadow, rather it is in a mesic upland/riparian area surrounded by quaking aspens. Hence, we would expect VWC to be lower than at Spooner Meadow. Indeed, VWC was similar to, but consistently lower than VWC measured in Plots 1 and 2, and was generally lower year-round than VWC in Plots 4 and 5 (Figure 7). However, VWC at the SNOTEL site was often higher than in Plot 3, indicating relatively drier conditions at Plot 3 compared to other mesic habitat.

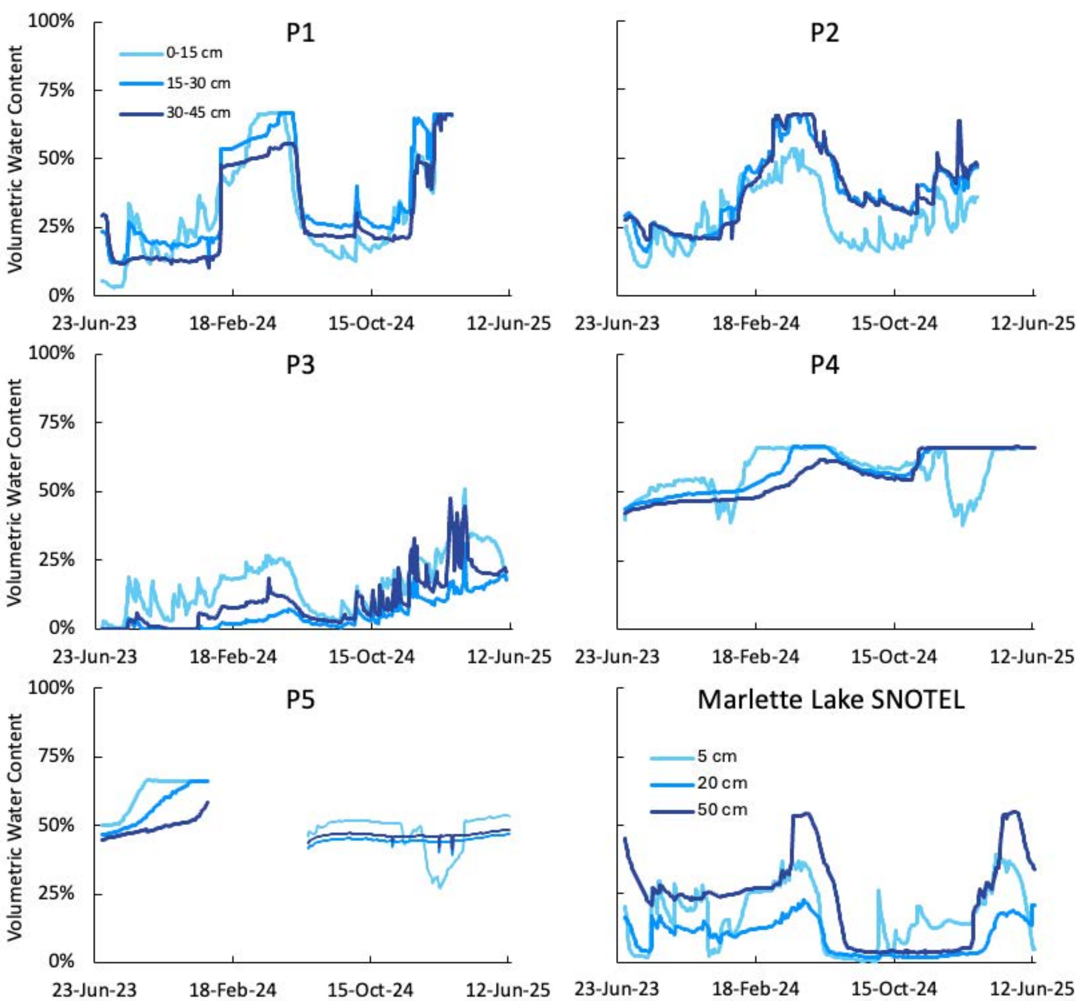

Figure 7. Soil moisture at each Study Plot (July 2023-June 2025). Soil moisture is shown here as the average daily volumetric water content (VWC) at three soil depths. Also included is soil moisture for three similar depths recorded at the Marlette Lake SNOTEL Monitoring Site for comparison. (SNOTEL data were converted from percent moisture to VWC using bulk density values available on the SNOTEL station website.)

Soil Temperature

There was pronounced seasonal variation in soil temperature at all plots, and ranges were similar across the meadow (Figure 8). Consistently, temperature was highest near the soil surface and decreased with soil depth. Soil temperature was higher in Plot 3 in summer months than at the other plots, as expected, due to its drier, upslope location. Peak soil temperature was slightly lower at Plots 4 and 5, where wetter conditions likely moderate summer temperatures. Soil temperatures were also very similar to, though slightly higher than, those at the Marlette Lake SNOTEL Monitoring Site.

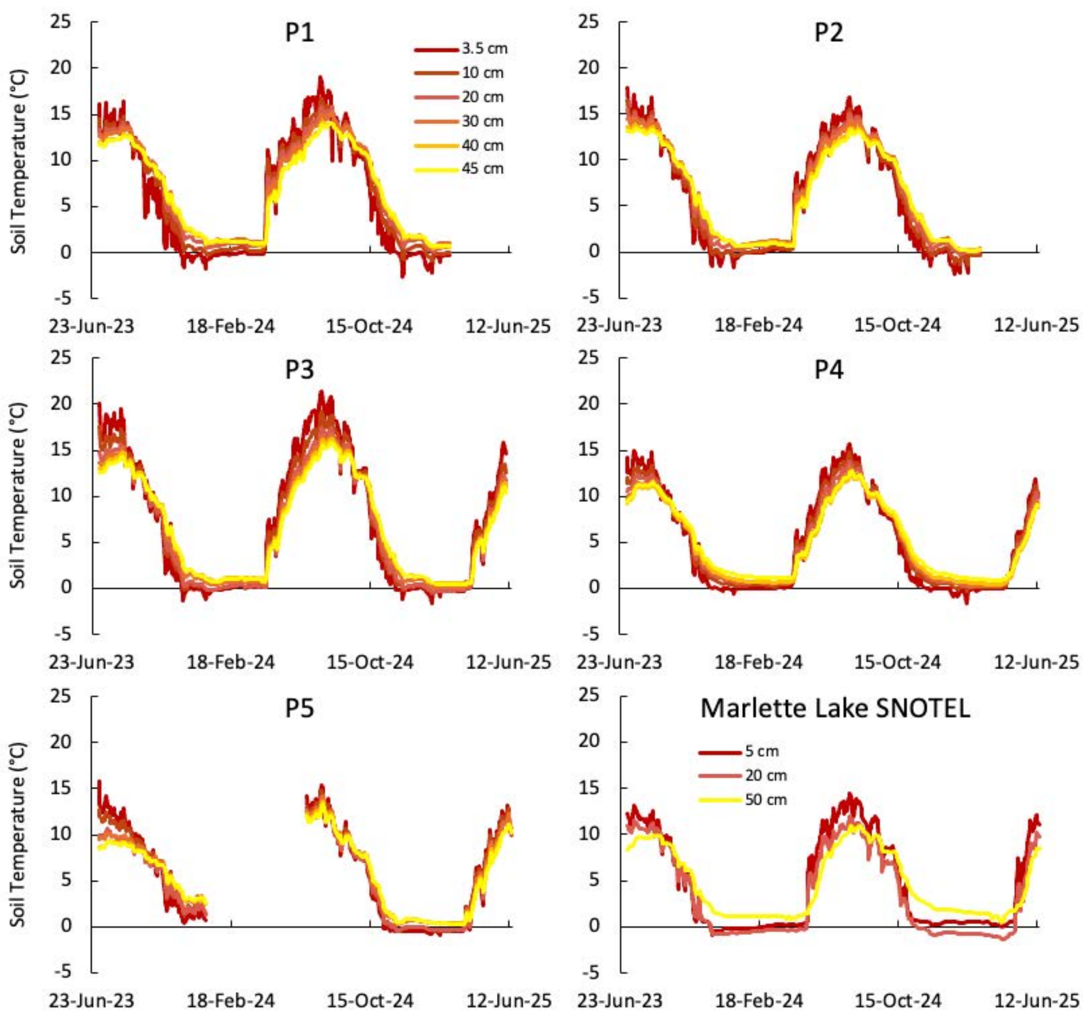

Figure 8. Soil temperature at each Study Plot (July 2023-June 2025). Temperature is shown as the average daily soil temperature measured at 6 depths. Soil temperature at three depths at the Marlette Lake SNOTEL Monitoring Site is included for comparison.

Primary Productivity

Primary productivity refers to the process of photosynthesizing organisms (e.g., plants) converting inorganic material (CO_2, sunlight, water, minerals) into new organic matter (i.e., plant biomass). This is a critical ecosystem function because 1) plant material is a fundamental component of ecosystem food webs, providing food resources to other organisms, 2) it is also a mechanism for sequestering carbon and buffering atmospheric CO_2, and 3) vegetation provides habitat and structure that facilitate other ecological functions and processes (e.g., biodiversity, nutrient cycling, species interactions). Montane meadows such as Spooner are highly productive ecosystems relative to the small geographic area they occupy in the landscape. Hence, we expect that Spooner Meadow provides outsized local and regional ecological benefits.

We used AGBM as a proxy for primary productivity. The AGBM data we collected at Spooner Meadow represent the amount of plant material present during the peak of the growing season in 2023 and 2024. Aboveground biomass varied between plots and between years (Figure 9). In 2023, average AGBM was 414 g m^{-2} and ranged from 332 to 497 g m^{-2} across plots. In 2024, average AGBM was 270 g m^{-2} and ranged from 85 to 463 g m^{-2} across plots. Aboveground biomass was similar in Plots 4 and 5 between years but substantially lower in Plots 1-3 in 2024 compared to 2023. These results suggest that there is environmental variation across the meadow that influences different rates of productivity and that annual growing conditions vary from year to year.

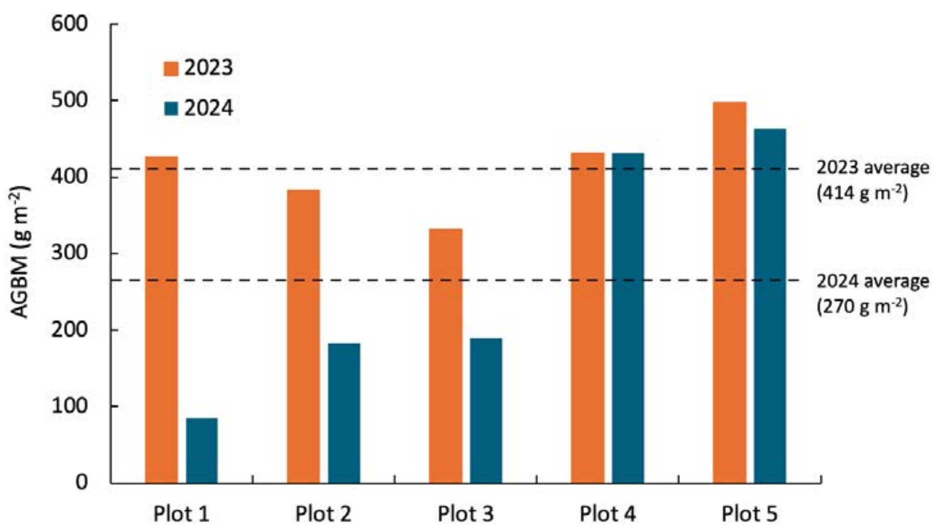

Figure 9. Aboveground biomass (AGBM) measured in each Study Plot in 2023 and 2024. The dotted lines show the average AGBM across Study Plots for each year.

To evaluate whether differences in AGBM between plots corresponded with environmental variation, we compared plot measurements of AGBM to soil moisture (Figure 10). We used soil sensor data from a depth range of 0-15 cm, averaged across the growing season (July-September in 2023 and June-September in 2024), which overlapped with the points in time when AGBM data were collected). In both years, higher soil moisture corresponded with higher AGBM. The positive correlation between soil moisture and AGBM was particularly strong in 2024 (R^2 = 0.80).

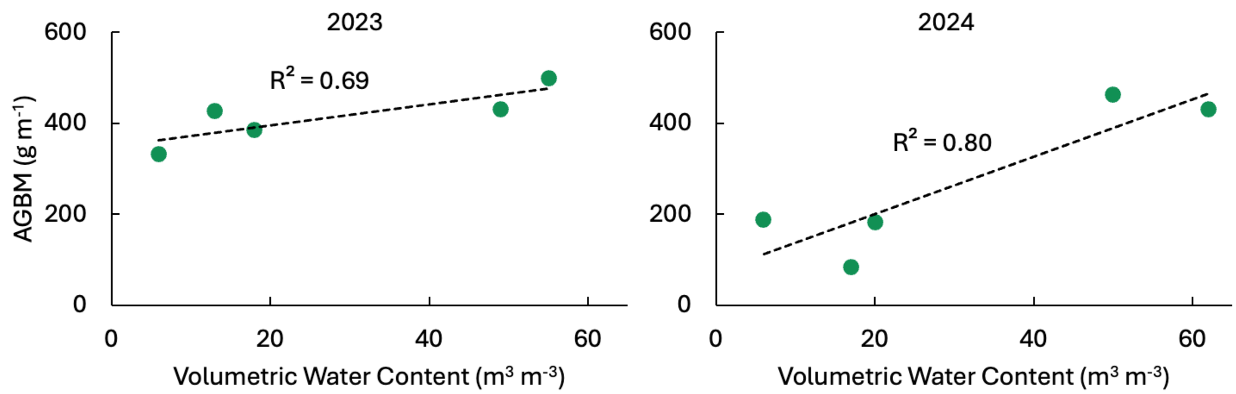

Figure 10. Relationship between plot measurements of aboveground biomass (AGBM) and soil moisture in 2023 and 2024. Soil moisture values are from the depth range of 0-15 cm, averaged across the growing season and measured as volumetric water content.

However, within plots, soil moisture was similar in both years. This suggests that soil moisture does not explain lower AGBM values in 2024 compared to 2023. (At lower depths, we found that soil moisture was actually higher in 2024 compared to 2023 across all plots.)

We also compared plot AGBM to soil temperature using near-surface soil temperature (3.5 cm depth), averaged across the growing season in 2023 and 2024 (Figure 11). There was a very strong correlation between AGBM and soil temperature in 2023 (R^2=0.95), but a much weaker correlation in 2024 (R^2=0.53).

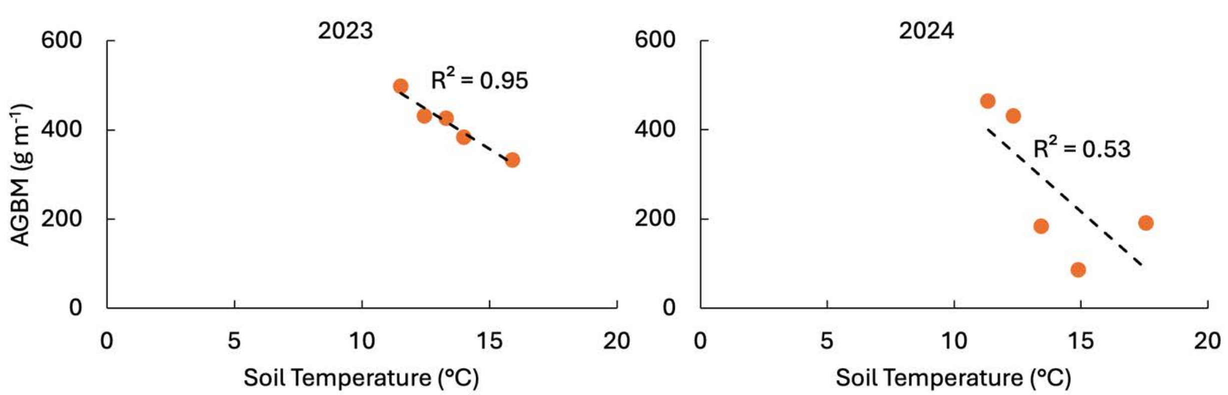

Figure 11. Relationship between plot measurements of aboveground biomass (AGBM) and soil temperature in 2023 and 2024. Soil temperature values are from a near-surface soil depth of 3.5 cm, averaged across the growing season.

Like soil moisture, soil temperature was similar within plots in both years. Aboveground biomass in Plots 1 and 3 in 2024 seem to be anomalies, potentially due to an inconsistency in field sampling by different field teams in 2023 and 2024. However, lower AGBM in Plot 3 in 2024 could be due to increased rodent activity that disturbed the ground; many burrows are present in that area.

To get a sense of how primary production in Spooner Meadow compares to that of other montane meadows, we compiled AGBM values reported in published studies (Table 3). Aboveground biomass at Spooner Meadow was within range of those reported for other meadows in the Sierra Nevada and montane meadows in other locations in the US.

Table 3. Comparison of aboveground biomass (AGBM) in montane meadows.

Montane meadow type	Location	Reported AGBM (g m^{-2})	Reference
Within the Sierra Nevada			
Restored riparian meadow	Northern Sierra Nevada, CA	516-719	Reed et al. 2022
Restored wet meadow	Tahoe National Forest, Sierra Nevada, CA	540	Maher 2015
Wet meadow	Sequoia National Park, Sierra Nevada, CA	377	Rundel 2015
Restored mesic meadow	Tahoe National Forest, Sierra Nevada, CA	240	Maher 2015
Outside the Sierra Nevada			
Riparian meadow	West Chicken Creek, northeast Oregon	809	Dwire et al. 2004
Riparian meadow	Limber Jim Creek, northeast Oregon	627	Dwire et al. 2004
Wet meadow	Middle Crow Creek Watershed, WY	360-532	Henszey et al. 1991
Moist meadow	Middle Crow Creek Watershed, WY	300-517	Henszey et al. 1991
Moist-wet meadow	Middle Crow Creek Watershed, WY	302-496	Henszey et al. 1991
Montane meadows (n=6)	West Elk Range, CO	50-350 (approx.)	Prager et al. 2021
Spooner Meadow	Lake Tahoe Basin, Sierra Nevada, NV	270-414[a]	This study

[a]Average values across plots in 2023 and 2024

Based on remote sensing RAP Production data (Table 2), annual total herbaceous production declined between 1986 and 2024, with the sharpest decline occurring in the last decade (2015-2024; Figure 12).

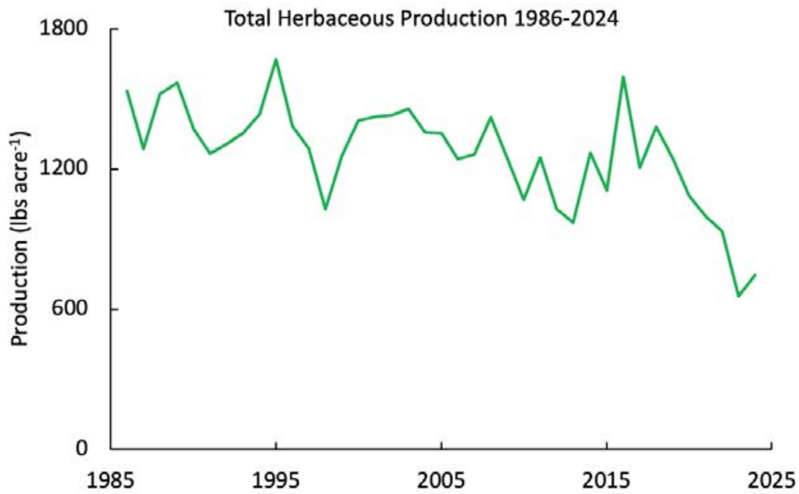

Figure 12. Annual total herbaceous production (1986-2024). Values are averaged across the Spooner Meadow study area.

This trend can also be observed in snapshots of spatial RAP production in 1986, 1999, 2012, and 2024 (Figure 13). Herbaceous production declined most notably in the top-center portion of Spooner Meadow, where the meadow steeply slopes into dry meadow/upland habitat dominated by shrubs and also in the northeast region of the meadow where shrub and tree cover are relatively dense.

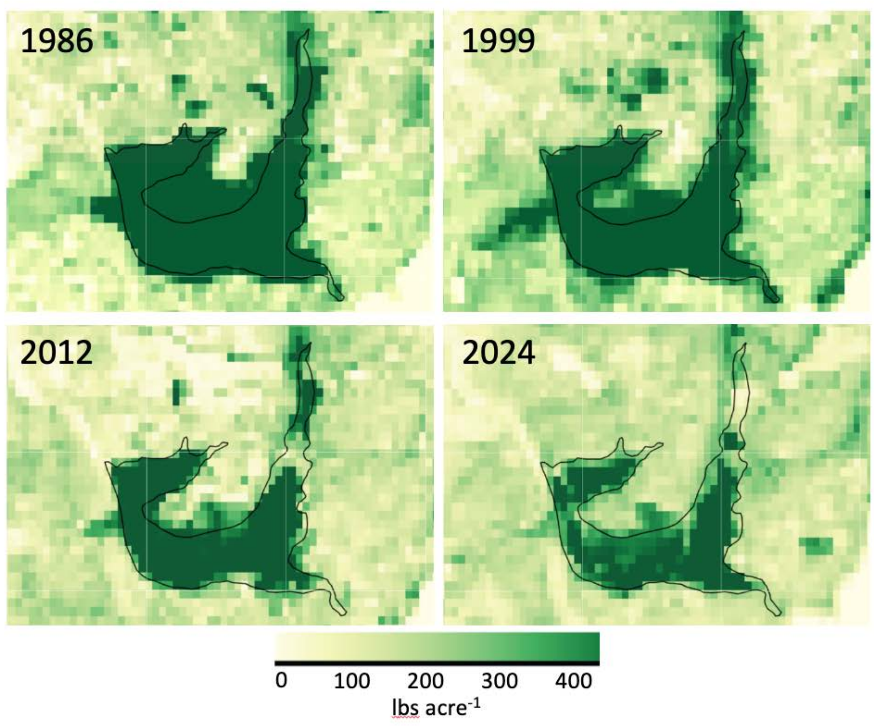

Figure 13. Snapshots of total herbaceous production in 1986, 1999, 2012, and 2024.

Meadow Habitat

A critical ecological function of montane meadows is providing habitat (i.e., food, water resources, shelter, favorable climate and environmental conditions) for species adapted to meadow settings. Healthy meadows are hotspots of biodiversity. They provide resources for resident species, such as meadow plants, insects, aquatic invertebrates, amphibians, and small mammals, as well as for non-resident species that visit meadows to forage, hunt, breed, and nest. We focused on measures of plant cover, density, biodiversity, and phenology to characterize Spooner Meadow habitat and used remote sensing data (NDVI) to assess vegetation health over time.

Plant Cover and Density

Percent cover is the estimated percent area that vegetation occupies within a defined unit area. It can be broken down by plant species, vegetation type, or total vegetation cover to capture different aspects of vegetation composition. Plant density refers to the number of plants per unit area. Together these measurements can provide a detailed picture of vegetation composition by accounting for larger plants that dominate space and smaller, finer plants (sedges, rushes, grasses) that may occupy less space in given area, but outnumber larger plants.

At Spooner Meadow, percent cover and density of vegetation types (grasses, forbs, rushes, and sedges) varied noticeably between plots (Figure 14). Overall vegetation cover was highest in Plot 2 (85%). Forbs occupied the most area in Plots 1 and 2 (54% and 50%, respectively), but were outnumbered by rushes. Plot 3, which was the driest plot, was the sparsest with only 47% vegetation cover. It was dominated by rushes and supported few forbs or sedges; however, it had the highest plant density, with approximately 1000 rush stems m^{-1}. Overall percent cover of vegetation was similar in Plots 1, 4, and 5 (70-76%), but Plots 4 and 5, which were the wettest plots, were dominated by sedges rather than forbs. Sedge density was also highest in Plots 4 and 5 compared to the other plots, although rushes were about equally common in Plot 4.

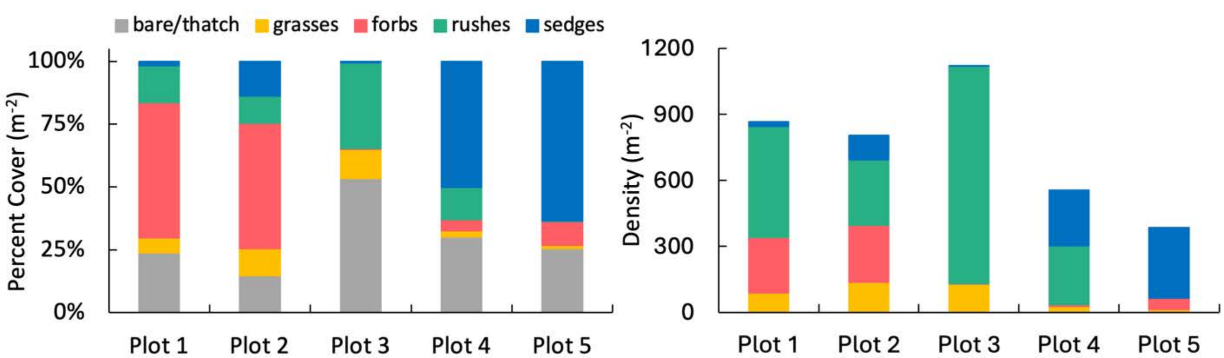

Figure 14. Percent cover and density of plant types in each Study Plot for 2023 and 2024 combined.

We compared percent cover in 2023 and 2024 to soil moisture and soil temperature to determine whether those soil characteristics influenced vegetation cover trends. Grass and forb cover generally declined with increased soil moisture both years (Figure 15). Forbs were dominant at VWC of 10-20%. Rush cover was highest at low VWC. Sedge cover increased noticeably with increased soil moisture both years. We found no clear trends with soil temperature.

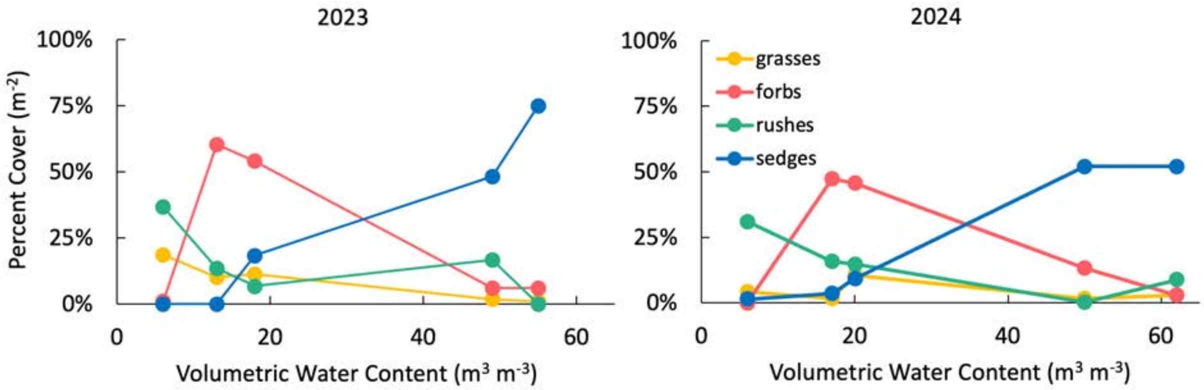

Figure 15. Relationship between percent cover and soil moisture in 2023 and 2024. Soil moisture values shown here are from the depth range of 0-15 cm, averaged across the growing season and measured as volumetric water content.

Plant Species Richness

Species richness is the number of unique species present in an ecosystem or area and is a simple measure of biodiversity. High species richness is often indicative of ecosystem health because it means that an ecosystem is sufficiently complex and dynamic to support a variety of species that play different roles in various ecological functions. In calculating species richness at each plot, we included species observed in quadrats during vegetation sampling as well as species observed in plots during informal surveys (Appendix A). We did not conduct formal surveys of entire plots or of the whole meadow. Thus, species richness counts underestimate the number of species present in plots and in the meadow at large. However, we can do relative comparisons between plots. A more comprehensive species list for Spooner Meadow can be found in the wetland delineation report (Hunter & Carpenter, Inc. 2009).

We observed the most plant species in Plots 1 and 2 (n=19 and 21, respectively) (Figure 16). Species common in Plot 1 included Baltic rush (*Juncus balticus*), plantainleaf buttercup (*Ranunculus alismifolius*), Rydberg's penstemon (*Penstemon rydbergii*), and western mountain aster (*Symphyotrichum spathulatum*). Species present in Plot 2 included plantainleaf buttercup, Rydberg's penstemon, long-stalked clover (*Trifolium longipes*) and Nebraska sedge (*Carex nebrascensis*). Species richness was lowest in Plot 3 (n=11); species found there included Baltic rush, sedges (*Carex* sp.), and tufted hairgrass (*Deschampsia caespitosa*). Plot 4 had slightly higher species richness compared to Plot 3 (n=12) and supported species such as Nebraska sedge, Baltic rush, and large-leaved avens (*Geum macrophyllum*). We identified 16 species in Plot 5, including Nebraska sedge, beaked sedge (*Carex utriculata*), duckweed (*Lemna* sp.) and American brooklime (*Veronica americana*).

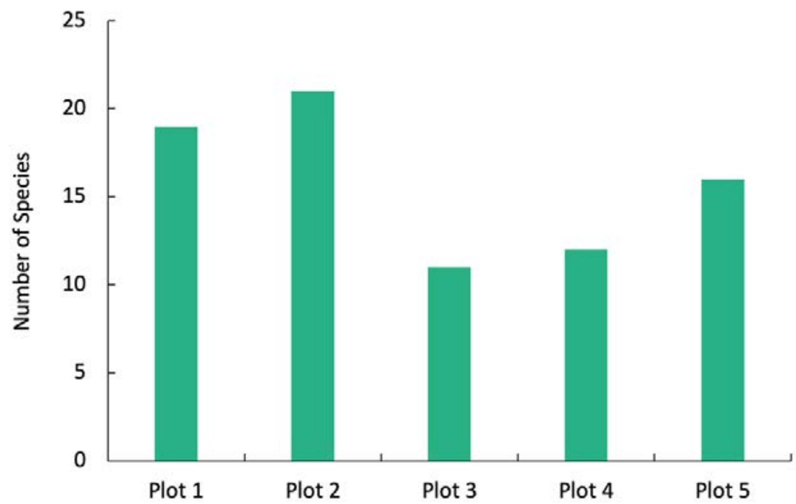

Figure 16. Plant species richness at each Study Plot.

We compared species richness to soil moisture and soil temperature to see if those soil characteristics influenced the number of species occurring in each plot. There was no linear relationship between species richness and soil moisture (VWC) or soil temperature (Figure 17). However, it is possible that a parabolic relationship exists between species richness and soil moisture (fewer species at levels of low and high soil moisture compared to moderate soil moisture), but more data are needed to confirm such a relationship.

We did find that species composition varied between plots: species composition was similar in Plots 1 and 2 and dominated by forbs. Between them, they had 7 species not found in the other plots. Plot 3 was dominated by graminoids. Only 1 unique species was present in Plot 4 (an unidentified species in the Asteraceae family), whereas Plot 5 had 8 species not found in the other plots. These species tended to be adapted to saturated conditions characteristic of that region of the meadow.

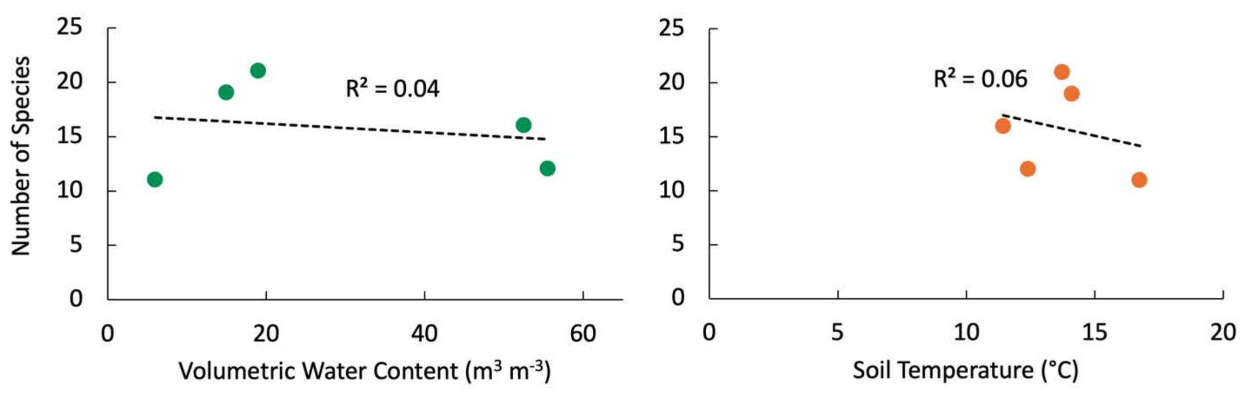

Figure 17. Plant species richness across soil moisture and temperature.

Plant Biodiversity

We used several biodiversity indices to quantify plant biodiversity in Spooner Meadow, based on species observed when measuring species density in quadrats. Plant species that were observed in Study Plots during informal surveys but not captured in quadrat sampling were not included in calculating indices because we did not record density values for those species. Thus, index values underrepresent biodiversity in the Study Plots. However, they still offer some insight into relative plant diversity between plots.

Shannon's Diversity Index (H) is a biodiversity index that accounts for both species richness (the number of species) and species evenness (the distribution of individuals among each species). The value range varies. Generally, values from 0 to 1 indicate low diversity; values from 2 to 4 indicate moderate to high diversity; values > 4 indicate very high diversity in relatively complex ecosystems. Plot 2 had the highest H value (2.04), suggesting moderate plant biodiversity, whereas Plot 3 had the lowest (0.46) (Table 4).

Margalef's Richness Index (R) is used to calculate species richness between sites because it can account for varying site size and sampling efforts. Higher values indicate greater species richness. We found that R was highest in Plot 2 (1.58) and similarly high in Plots 1 and 5.

Pielou's Evenness Index (E) accounts for the evenness of species in a community, or sampled area, rather than just the number of species present. A value near 1 indicates an even distribution of species; values < 0.5 indicate that a community or area is dominated by one or few species. Plot 2 had the highest E value (0.80), indicating species were most evenly distributed in that plot. Evenness was lowest in Plot 3 (0.24) due to the plot area being overwhelmingly dominated by Baltic rush. Although Plot 5 had a relatively high R value, its relatively low E value accounts for that plot being dominated primarily by Nebraska sedge and beaked sedge, with few individuals of other species present.

Table 4. Biodiversity indices for Study Plots (2023 and 2024 combined)[a].

Plot	No. species	H[b]	R[c]	E[d]
1	12	1.42	1.43	0.57
2	13	2.04	1.58	0.80
3	7	0.46	0.76	0.24
4	8	0.97	0.97	0.47
5	12	1.07	1.45	0.45

[a]Index values were calculated using only species that were captured in density measurements during quadrat sampling. The total number of species observed in plots was higher than the number identified in quadrats, hence counts under 'No. species' are lower than counts of species richness analyzed above.
[b]Shannon's Diversity Index
[c]Richness Index
[d]Evenness Index

Plant Phenology

Plant phenology refers to the seasonal timing of plant development (e.g., bud break, flowering, fruiting, leaf/plant senescence). Pollinator life cycles, herbivore activity, and movement of migratory species are generally synched with plant phenology. Hence, phenology is a critical component of habitat and other ecosystem functions. Seasonal environmental factors such as temperature, photoperiod, and precipitation influence phenology. In Spooner Meadow, snowpack is also an important influence on plant phenology (Kittel 1998).

In 2023, we did not begin collecting phenology measurements until August and missed the peak flowering window. However, we still found that approximately 45% of plants sampled in subplots were flowering in August (primarily tufted hair grass, Parish's yampah (*Perideridia parishii*), western mountain aster, and Baltic rush (*Juncus balticus*)), whereas about 50% had gone to seed. By September only ~1% of sampled plants were flowering; 54% had set seed and the remainder were in some stage of senescence (indicated by yellowing, dry vegetation). By October, 72% of sampled plants were senescing.

During the following year (2024), flowering peaked in June (90% of sampled plants; species not recorded) and dropped to 39% by July, when 32% were fruiting and 29% showed signs of senescence. By September 2024, 74% of sampled plants were in a stage of senescence; this amount of senescing plants occurred a month earlier compared to 2023. This indicates the growing season was extended in 2023 compared to 2024, due to the record snow year (and subsequent snowmelt) in 2023. In 2025, we made general phenology observations and noted that flowering was dominated by plantainleaf buttercup across much of the meadow in May. Several species seemed to be in peak flowering stage by mid-June: Rydberg's penstemon, blue grasses (*Poa* spp.), and numerous sedges (Nebraska sedge, beaked sedge, water sedge (*Carex aquatilis*), and slender beak sedge (*C. athrostachya*)).

Trends were similar between plots; timing of flowering/fruiting/senescing was not noticeably earlier or shorter in any plot.

Insect Observations

One of the student research assistants who worked on this project had an interest in entomology and identified insect species when out doing fieldwork in 2025 (Table 5). The insects observed included many important pollinators, such as several Lepidopterans and Yellow-faced bumble bee. The presence of insects in the order Odonata (dragonflies, damselflies) at Spooner Meadow is a good indicator of meadow health. They are sensitive to water quality and habitat degradation, and they regulate aquatic food webs. Thus, their presence can be a useful measure of habitat condition in different region of the meadow.

Table 5. List of insects observed at Spooner Meadow in 2025.

Order	Family	Species	Common Name
Coleoptera	Coccinellidae	*Coccinella septempunctata*	Seven-spotted lady beetle
Coleoptera	Melyridae	*Listrus* sp.	Soft-winged flower beetle
Diptera	Bombyliidae	*Lordotus diplasus*	Bee fly
Hymenoptera	Apidae	*Bombus vosnesenskii*	Yellow-faced bumble bee

Lepidoptera	Hesperiidae	*Polites sonora*	Sonoran skipper
Lepidoptera	Lycaenidae	*Icaricia icarioides*	Boisduvals blue
Lepidoptera	Papilionidae	*Papillo eurymedon*	Pale swallowtail
Lepidoptera	Papilionidae	*Papillo rutulus*	Western tiger swallowtail
Lepidoptera	Pieridae	*Colias eurytheme*	Orange sulphur
Lepidoptera	Pieridae	*Pieris rapae*	Cabbage white
Lepidoptera	Pterophoridae	*Platyptilia carduidactyla*	Artichoke plume moth
Odonata	Aeshnidae	-	Dragonflies (darners & hawkers)
Odonata	Coenagrionidae	*Enallagma carunculatum*	Tule blue
Orthoptera	-	-	Grasshoppers (nymphs)

Vegetation Health

The remote sensing index, NDVI, measures the greenness of vegetation, which is used to assess vegetation health. Values of NDVI range from -1.0 to 1.0 with higher values corresponding with greener, denser vegetation. Values < 0 indicate bare rock, water, or snow. Low positive values (0.1-0.4) correspond with sparse or stressed vegetation. Values ranging from 0.4 to 0.6 indicate moderately healthy vegetation with potential mild stress. Values > 0.6 indicate healthy, dense vegetation with no apparent stress. A sudden drop in NDVI in an area could signal a disturbance that is causing stress, such as a drought, fire, or pest outbreak. Consistently low NDVI values over time could signal a chronic stress, such as altered hydrology or overgrazing. Healthy montane meadows in the Sierra Nevada generally have an NDVI value around 0.6.

NDVI values for the growing season (June to September) varied within Spooner Meadow but were relatively consistent over time (1986-2024; Figure 18). The western portion and southern edge of the meadow had the highest NDVI values, reaching ~0.7. These green, dense, healthy areas follow the flow of North Canyon Creek. The central portion of the meadow, which is upslope and considered mesic meadow rather than wet meadow, had NDVI values ranging from 0.2 to 0.5. This suggests that the vegetation there was sparser or stressed, likely due to drier, upslope conditions.

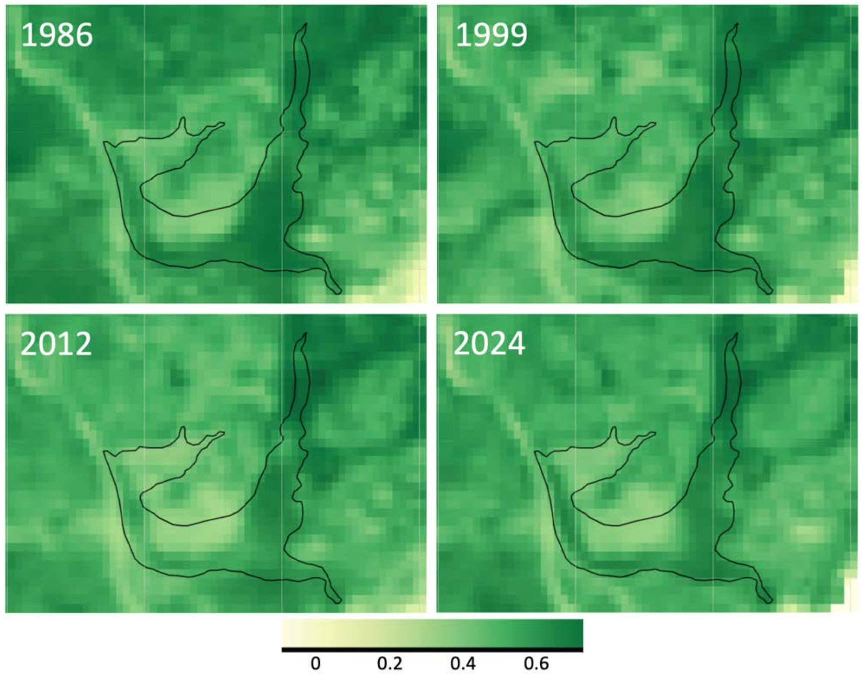

Figure 18. Snapshots of NDVI during the growing season (June to September) in 1986, 1999, 2012, and 2024.

Decomposition

Decomposition, or the breaking down of organic matter, is an essential component of the carbon cycle. Whereas primary productivity involves fixing atmospheric CO_2 and storing it in biomass via photosynthesis, the process of decomposition includes returning carbon to the atmosphere. Decomposition is also important in nutrient cycling; as microbes break down organic matter, nutrients such as nitrogen, phosphorus, and sulfur are converted back to forms that primary producers can use. The rate of decomposition largely depends on temperature, oxygen, and moisture. Matter decomposes fastest under warmer, aerobic conditions with moderate moisture. Under saturated, anaerobic conditions found in wetland soils, including meadows, decomposition occurs more slowly, allowing organic matter to build up and carbon to be stored.

At Spooner Meadow, we found that the rate of decomposition slowed over time during the first round (R1) of tracking litter bags (Figure 19). Litter bags were deployed in July 2023 and collected in September, November, May, June, and August. During that time the rate of decomposition decreased from 0.39 g wk^{-1} to 0.11 g wk^{-1}. The percent of material that had decomposed over time ranged from 33% after 8 weeks to 60% after 56 weeks. We would expect this pattern given that litter material began decomposing during summer and fall months when warm, dry conditions facilitated the fast break down of the highest quality litter in the litter bags. Decomposition would have paused during winter and resumed as temperatures increased in spring; however, by then the remaining litter may have been of lower quality (i.e., more difficult to break down). We deployed bags for the second round (R2) in August 2024 and collected litter bags in December, March, May, and June. We saw a consistent, and much slower, rate of decomposition during that round (0.15 to 0.11 g wk^{-1}), likely because much of the deployment occurred during winter months. The percent of material that had decomposed during R2 ranged from 24% after 16 weeks to 55% after 43 weeks.

We expected to see the fastest rate of decomposition at Plot 3, which was more exposed and drier, and slowest decomposition rates at Plots 4 and 5, which were most frequently saturated. However, there was no clear trend between plots. During the decomposition study, several bags went missing or showed signs of damage, particularly litter bags deployed at Plot 3 where there were many rodent burrows (potentially from pocket gophers). Missing and damaged litter bags were not included in data analysis, which makes it difficult to draw conclusions on temporal and spatial decomposition trends in the meadow.

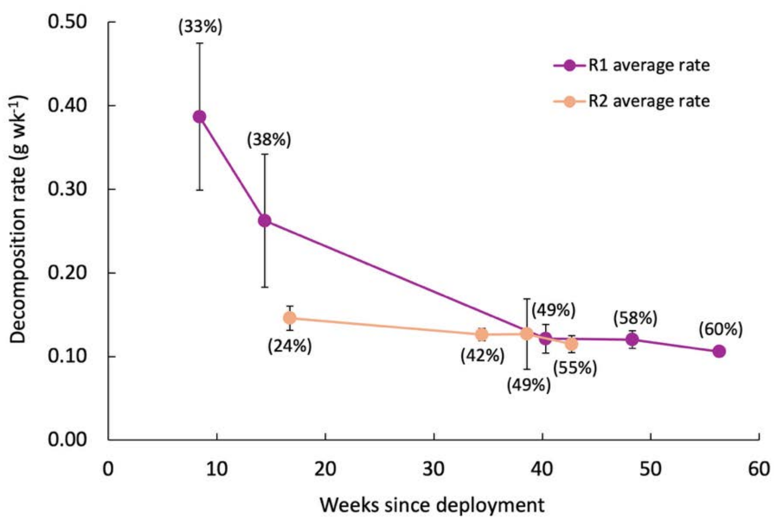

Figure 19. Decomposition rates measured at Study Plots. Average rates (points) and standard deviations (bars) are based measurements from litter bags deployed July 2023-August 2024 (R1) and August 2024-June 2025 (R2). The average percent of decomposed material is shown in parentheses.

Shrub and Tree Encroachment

Shrubland adjacent to Spooner Meadow was dominated by sagebrush (*Artemisia tridentata*) and bitterbrush (*Purshia tridentata*). TMCC students found shrub density from just outside the meadow toward the interior of the meadow decreased from 0.33 m^2 to < 0.01 m^2. Average peak percent cover across transects (51%) occurred in uplands adjacent to the meadow (Figure 20). Seedlings were found along the upland and upland/meadow transition segments of the transects, suggesting shrub cover may increase over time. Students identified larger areas of shrub cover in 2020 compared to 1969, based on aerial imagery.

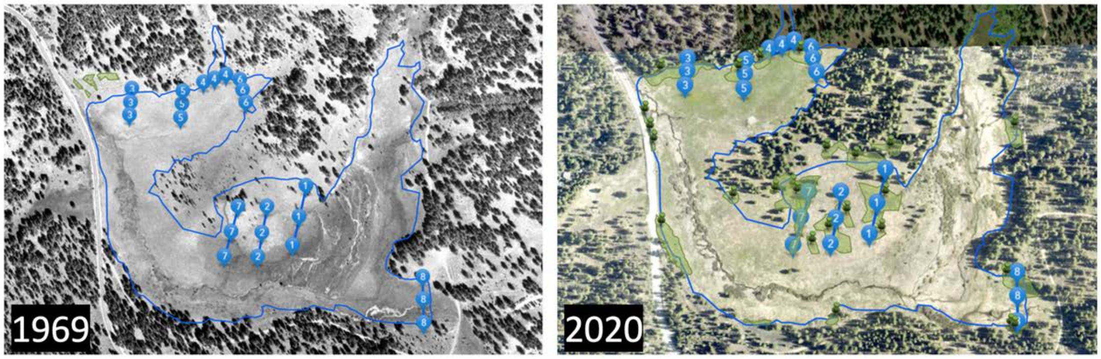

Figure 20. Comparison of shrub encroachment in 1969 and 2020. Numbered lines show transects where students collected field data. Green polygons show shrub cover mapped by students. The blue line shows the shrub encroachment study area.

Forest surrounding Spooner Meadow is dominated by lodgepole pine (*Pinus contorta*) and North Canyon Creek supports patchy riparian corridors dominated by willows (*Salix* spp.) and quaking aspen (*Populus tremuloides*). Based on remote sensing RAP Tree Cover data (Table 2), percent tree cover increased from ~4% to 25% since 1986. Tree cover increased steadily from 1986 to 2011 (Figure 21). Since 2012, tree cover has fluctuated and sharply increased to 25% in 2023. However, given the coarse spatial resolution of the dataset (30 m), a more detailed field study with high-resolution imagery would be necessary to accurately evaluate tree encroachment trends into Spooner Meadow.

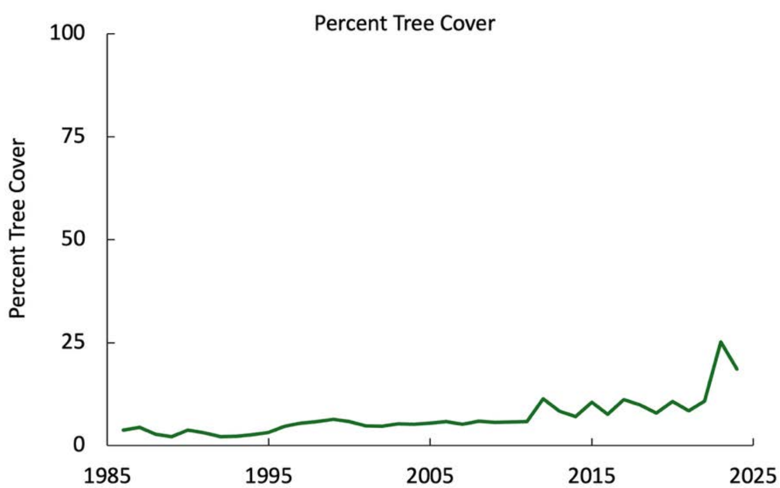

Figure 21. Percent tree cover (1986-2024). Tree cover estimated from remote sensing analysis using the RAP Tree Cover dataset.

Spatially, percent tree cover increased most clearly in the northeastern portion of the meadow over time (Figure 22). Tree cover also generally increased along North Canyon Creek across the meadow. Many willows were observed in the meadow along North Canyon Creek and associated tributaries during this study. Increased tree cover over time could be the result of a more pronounced riparian corridor forming from increased willow cover, especially in the western region of the meadow, rather than from encroaching conifers.

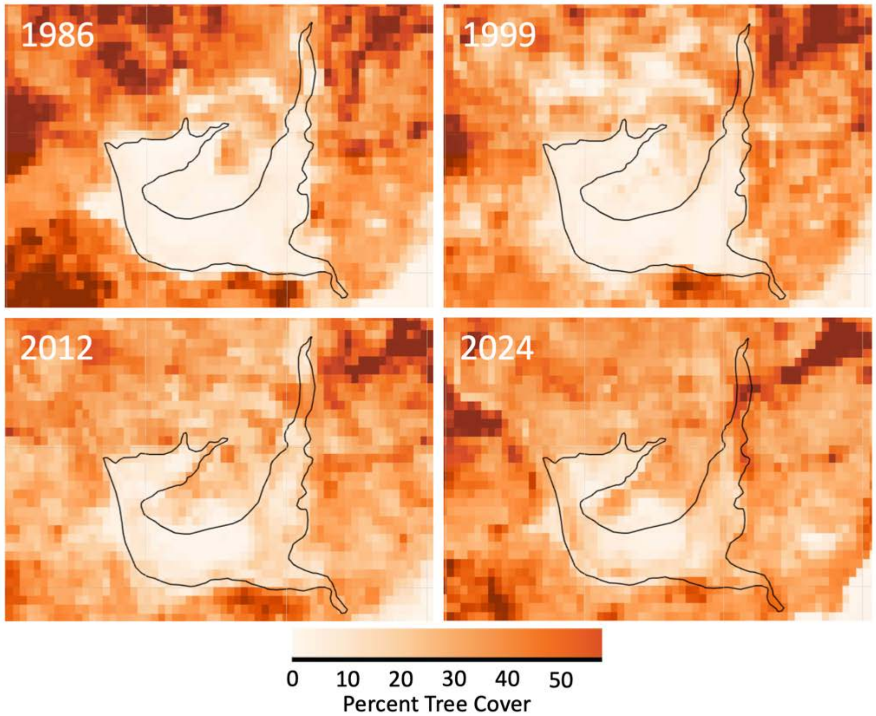

Figure 22. Snapshots of percent tree cover in 1986, 1999, 2012, and 2024.

Water Quality of North Canyon Creek

North Canyon Creek is a 5.5-mile stream that flows from Snow Valley Peak, through Spooner Meadow, and through Slaughterhouse Canyon before flowing into Lake Tahoe. It is listed as a Category 5 waterbody by the EPA, meaning it is impaired or threatened by pollutant(s) for at least one designated use and requires a total maximum daily load (TMDL). North Canyon Creek has been identified as not supporting aquatic life (NDEP 2022), due to a high concentration of iron. Iron concentration in the water exceeds 0.1 of the 96-hour median tolerance limit for fish and other aquatic organisms (EPA 1988, NDEP 2022). Although iron is an essential nutrient for organisms, elevated concentrations can be toxic for fish and other aquatic life. High concentrations can also cause bacterial outbreaks and algal blooms, which can impair water quality by reducing oxygen levels in the water and increasing sediment concentrations.

For assessing the water quality of North Canyon Creek, we focused on three measurements among those we collected: dissolved oxygen (mg L^{-1}), conductivity (μS cm^{-1}), and total dissolved solids (mg L^{-1}). These are commonly used as metrics for evaluating water quality and can be compared to other surface waters in the region. Because they are generally reliable, consistent measurements that are relatively easy to interpret, they can be useful for tracking water quality and aquatic habitat health. They are often used to compare against standard values, annual averages, or set target values for monitoring programs or hydrology assessments (Timmer et al. 2006, TRPA 2006, TRWC 2020, Vidra 2015). These water quality measurements are also affected by water temperature, which varied seasonally from 0 to 22 °C (32 to 72 °F) (Figure 23). The upstream sampling location was under tree canopy, which buffered the water temperature from hot and cold air temperatures and likely influenced water quality readings. The other sampling locations were away from canopy cover and exposed to direct sunlight. In these locations, water temperature was directly affected by air temperature fluctuations, which indirectly influenced water quality readings.

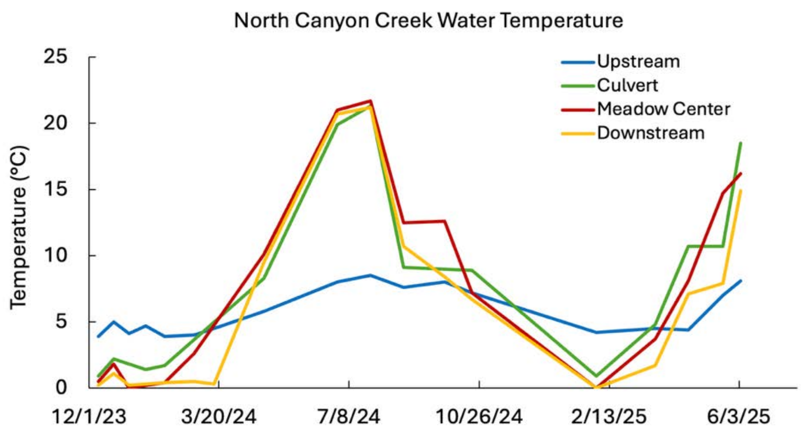

Figure 23. Water temperature at water quality sampling locations (Dec 2023-June 2025).

Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen available in a waterbody for aquatic organisms to use for respiration (i.e., to breathe). Dissolved oxygen is critical for organism survival, reproduction, and growth, and for supporting aquatic biodiversity and maintaining healthy food webs in aquatic systems (Timmer et al. 2006). Different aquatic organisms require different levels of DO. Trout and stoneflies, for example, require relatively high levels of DO, whereas other organisms such as mosquitofish and leeches tolerate relatively low levels of DO. Generally, DO below 6 mg L^{-1} is considered harmful to aquatic organisms; in low DO environments, there is not enough oxygen available for organisms to survive. Conditions such as pollution, eutrophication, algal blooms, and warm water temperatures cause low DO environments.

Dissolved oxygen changes with temperature; colder water holds more oxygen than warmer water. For example, water with a temperature of 0 °C (32 °F) holds > 14 mg L^{-1} of DO, whereas water with a temperature of 20 °C (68 °F) holds approximately 9 mg L^{-1}(APHA 1992). Hence, daily and seasonal variation should be expected in DO levels of North Canyon Creek.

For tributary streams in the Lake Tahoe Basin, the standard for DO is > 6.0 mg L^{-1} (TRPA 2006). Along North Canyon Creek, DO was typically between 6 and 15 mg L^{-1} (Figure 24). Within this DO range, the creek can provide fair to excellent conditions for aquatic organisms. However, there were a couple high DO outlier values in July and August 2024 at the upstream sampling location; given that DO in the other sampling locations was among the lowest recorded during the study, these were likely falsely high values. The low DO values in July and August 2024 corresponded with the highest water temperatures measured in North Canyon Creek during the study (20-22 °C/69-71 °F), when we would expect DO to be low. It is unclear why DO was so low (~3 mg L^{-1}) at the upstream sampling location in March 2025. Low DO values may also be related to elevated iron concentrations in North Canyon Creek (NDEP 2022). However, we occasionally had technical issues with the DO sensor on the water quality meter, which may have affected DO measurements in general. Hence, the DO readings should be used with caution.

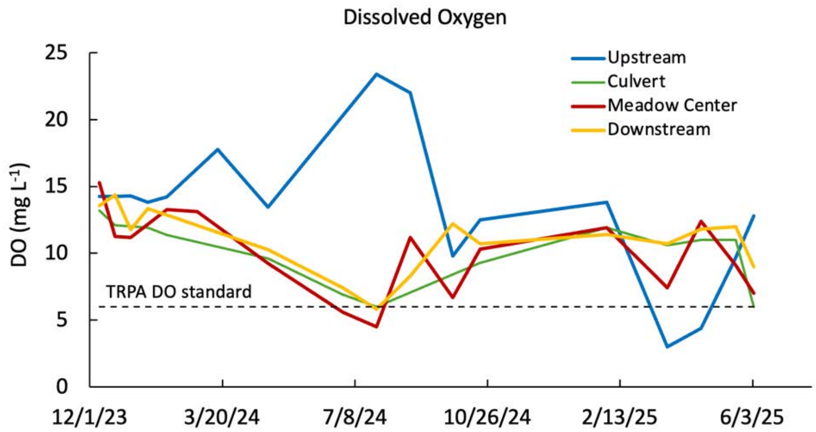

Figure 24. Dissolved oxygen at water quality sampling locations (Dec 2023-June 2025). The dashed line shows the minimum DO standard stated in the 2006 Threshold Evaluation Report (TRPA 2007) and set by the Nevada Division of Environmental Protection (NDEP).

Conductivity

Conductivity refers to the ability of water to conduct electricity. It is driven by the amount of charged particles (ions) in the water, such as chloride, calcium, sodium, and sulfate. In cold creeks and streams, conductivity is largely affected by the composition of rocks and soil that the water flows through. However, conductivity is also influenced by human activities. High conductivity is indicative of impaired water quality; high concentrations of ions may be caused by runoff, sewage, industrial discharge, or sediment contaminating the waterbody. In the Lake Tahoe Basin, road salts and sands may be primary causes of high conductivity, as they are in the Truckee River watershed (TRWC 2020). Like DO, conductivity is also affected by temperature; conductivity is higher in warmer water than in colder water.

For reference, distilled water has a conductivity range of 0.5 to 3 μS cm^{-1} (microSiemens per centimeter). Freshwater streams providing healthy habitat for aquatic organisms have conductivity values ranging from 150 to 500 μS cm^{-1} (APHA 1992). However, cold mountain streams tend to have quite low levels of conductivity (closer to 10 μS cm^{-1}), especially during low flow conditions, and is indicative of healthy conditions. For example, Cascade Creek and Eagle Creek in the South Lake Tahoe region each had a conductivity value of 10 μS cm^{-1} when monitored in 2015 (Vidra 2015). Several tributaries in the Truckee River watershed have also had similarly low conductivity values during low flows (TRWC 2020).

In North Canyon Creek, conductivity was consistent over time at the upstream sampling location, with values averaging 65 μS cm^{-1} (Figure 25). Conductivity was consistently highest at the culvert location, through which water from Spooner Lake flows. We observed a spike in conductivity in Summer 2024, likely due to warm summer temperatures that increased evaporation and water temperature, which could have increased the concentration of ions in North Canyon Creek. High iron concentration in the water could also contribute to high conductivity readings. However, conductivity was generally well below the standard value of 500 µS cm^{-1} for healthy freshwater streams.

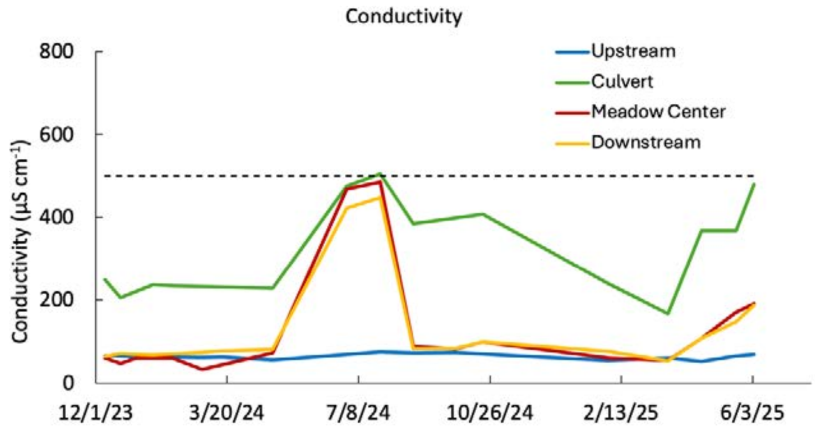

Figure 25. Conductivity at water quality sampling locations (Dec 2023-June 2025). The dashed line shows the maximum conductivity for healthy freshwater streams (500 µS cm^{-1}) (APHA 1992).

Total Dissolved Solids

Total dissolved solids (TDS) is the total amount of inorganic and organic matter dissolved in water, typically small enough to pass through a filter of 2 microns. Because TDS material is small, it generally does not affect water clarity (i.e., it is not a measure of turbidity), rather it affects water chemistry and affects measurements such as conductivity. Total dissolved solids include ions like calcium, sodium, chloride, as well as dissolved organic material. These particles enter waterbodies from sources such as road salt, agricultural runoff, industrial discharge, and mineral weathering. Concentration of TDS is indirectly affected by water temperature (warmer water can dissolve more solids than colder water) and increased microbial activity, which releases dissolved organic matter. Additionally, in warmer weather, evaporation can increase TDS concentration, whereas spring snowmelt can dilute TDS concentration.

Healthy waterbodies in Nevada should have TDS concentrations below 500 mg L^{-1} (Vidra 2015). However, stricter thresholds exist for waters in the Lake Tahoe Basin because Lake Tahoe has a standard of 70 mg L^{-1} (Vidra 2015). Water quality control points at Incline Creek, First Creek, Second Creek, Third Creek, and Wood Creek have had TDS standards ranging from 70 to 90 mg L^{-1} and annual average standards ranging from 55 to 80 mg L^{-1} (TRPA 2006).

Concentrations of TDS solids were well below the Nevada standard of 500 mg L^{-1} at all sampling locations along North Canyon Creek and followed a pattern very similar to conductivity (Figure 26). Concentrations of TDS were consistently greatest at the culvert sampling location, ranging from 176 to 382 mg L^{-1}. At the other locations, TDS was generally close to the Lake Tahoe standard of 70 mg L^{-1}. This indicates that TDS was much higher in Spooner Lake than North Canyon Creek, since water from Spooner Lake flows through that culvert. During July and August 2024, TDS spiked at the upstream, meadow center, and downstream locations. Most likely, summer temperatures increased evaporation and water temperature, increasing the concentration of dissolved matter and microbial activity, which resulted in higher TDS concentrations.

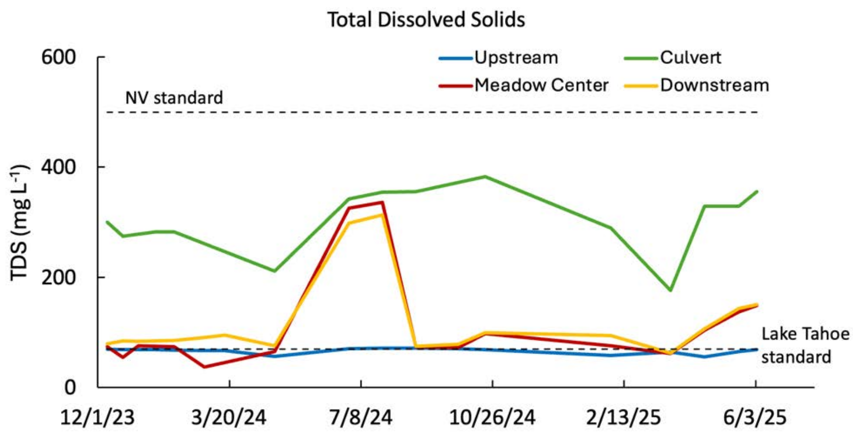

Figure 26. Total dissolved solids (TDS) at water quality sampling locations (Dec 2023-June 2025). The dashed line at 70 mg L^{-1} is the Lake Tahoe standard. The dashed line at 500 mg L^{-1} is the Nevada State standard.

2023-2025 Snowpack

Snowpack varied substantially during this study: snowpack in 2023 was one of the largest on record. Snowpack measurements in 2024 and 2025 were closer to normal. We used snow depth and snow water equivalent data from the Marlette Lake SNOTEL Monitoring Site to characterize local snowpack conditions for 2023-2025. At the SNOTEL station, snow depth reached 3.4 m and SWE peaked at 134 cm in 2023 (Figure 27). During the following two winters, snow depth reached approximately 2 m and SWE reached 60 cm.

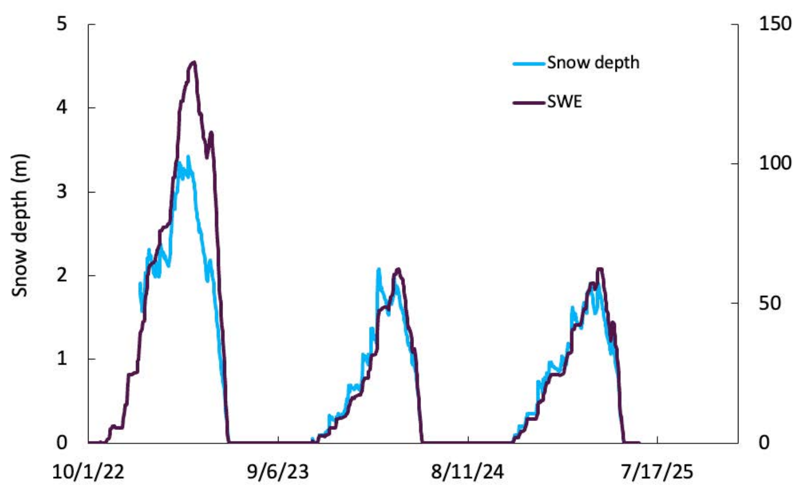

Figure 27. Snowpack at the Marlette Lake SNOTEL Monitoring Site (2023-2025). Snowpack was measured as snow depth (left y-axis) and snow water equivalent (SWE; right y-axis).

Across Spooner Meadow, we found that snow depth ranged from < 0.1 to 2.5 m in 2024, based on depths measured near study plots and water quality sampling points. In 2025, snow depth ranged from 0.15 to 0.4 m, based on depths measured in randomly selected locations and near study plots.

Because fieldwork for this study did not begin until July 2023, we do not have meadow snow depth measurements for 2023.

SUMMARY OF BASELINE CONDITIONS AT SPOONER MEADOW

This baseline study of Spooner Meadow assessed primary productivity, habitat, including vegetation cover and density, biodiversity, and phenology, as well as rates of decomposition. These functions and processes were evaluated in the context of soil characteristics, local weather conditions, and long-term environmental and vegetation trends. This study also assessed baseline water quality characteristics of North Canyon Creek from immediately upstream of Spooner Meadow, through the meadow, and immediately downstream of the meadow.

Summary of Study Plots

We found that ecological functions and processes were influenced by varying vegetation, soil, and hydrology characteristics across Spooner Meadow, as captured in the five Study Plots (Figure 2). Study Plots 1 and 2 were located in the western portion of the meadow at similar elevations and occurred in hydric soil. Study Plot 1 captured conditions of wet meadow away from the main channel of North Canyon Creek, whereas Plot 2 captured conditions close to North Canyon Creek. Soil moisture and temperature characteristics were similar at these two plots: VWC was 0-25% in summer and fall months, and peaked at 65% during the spring. Soil temperatures peaked around 17 °C (63 °F) in summer months and dropped below 0 °C (32 °F) in winter months.

Both Plots 1 and 2 supported relatively high AGBM (proxy for primary production) in 2023, but it was much reduced in 2024. Habitat at Plot 1 consisted of relatively high percent cover of meadow vegetation (76%). It was dominated by native forbs and supported relatively high plant diversity. It also supported a few non-native grasses and at least 1 non-native forb that occurred in low density (Appendix A). Plot 2 was also dominated by native forbs and had the highest vegetation cover (85%) and highest degree of plant diversity (21 species; Shannon's H: 2.04). Like Plot 1, it contained a few non-native grasses and forbs in low density.

Study Plot 3 was located near the center of the meadow on non-hydric soil. It represented upslope, mesic meadow conditions away from North Canyon Creek. Plot 3 had the driest, warmest soil conditions among the Study Plots (VWC was 0-50%, near-surface soil temperature > 20 °C (> 68 °F)). There was also less seasonal variation in soil moisture in Plot 3 compared to Plots 1 and 2. Aboveground biomass was lowest in Plot 3 and substantially lower in 2024 than in 2023. Habitat at Plot 3 included relatively sparse vegetation (47% vegetation cover) and relatively low plant diversity (11 species; Shannon's H: 0.46), dominated by rushes. At least one non-native annual grass (not identified to species) occurred in Plot 3 in low density. There was a noticeable amount of ground disturbance in and around Plot 3 from animal burrows that likely influenced vegetation cover.

Study Plots 4 and 5 were located in the eastern portion of Spooner Meadow in hydric soil. They represented wet meadow conditions near North Canyon Creek at higher elevations than Plots 1 and 2. At both plots, seasonal soil moisture and temperature seemed to be moderated by North Canyon Creek (VWC was 40-65% throughout the year; summer temperatures were typically < 15 °C (< 59 °F)) and near 0 °C (32 °F) in winter). Aboveground biomass was consistently high in these two plots in 2023 and 2024 and AGBM was highest in Plot 5 both years. In terms of habitat, Plot 4 had 70% vegetation cover, was dominated by sedges and had lower plant diversity than most other plots. Plot 5 had approximately 75% vegetation cover and was also dominated by sedges. However, plant diversity was higher than in Plot 4. Like Plot 3, at least one non-native annual grass was present in low density in Plots 4 and 5.

Ecological Characteristics Across Spooner Meadow

Across Spooner Meadow, AGBM was similar to AGBM values reported for other meadows in the Sierra Nevada (Table 3). Aboveground biomass increased with soil moisture (Figure 10) and decreased with soil temperature (Figure 11). Vegetation cover and composition varied across the meadow in response to soil moisture (Figure 15). Grass cover was relatively low across the meadow and declined with increased soil moisture. Forb cover was relatively high in areas with moderately low soil moisture. Rushes were dominant under the driest soil conditions and sedges dominated areas with the wettest soils. No clear trends in phenology or decomposition were observed with respect to environmental conditions across the meadow. No areas dominated by non-native, invasive plant species were observed in the meadow during the study.

Several temporal vegetation trends were notable at Spooner Meadow. Herbaceous plant production declined over time (1986-2024), particularly in the mesic meadow region and in the northwest corner along the riparian corridor of North Canyon Creek (Figures 12, 13). Shrub cover has increased in upland areas adjacent to the meadow and may be increasing along the mesic fringes of the meadow (near Study Plot 3; Figure 20). Tree cover has increased since 1986 and most sharply in the past several years (Figure 22). This may be indicative of a denser willow-dominated riparian corridor developing along the portion of North Canyon Creek that runs through the meadow. Vegetation health, as measured by NDVI, has been relatively consistent since 1986 (Figure 18). Most of the wet meadow region has maintained an NDVI value around 0.7, indicating no apparent vegetation stress. However, NDVI in the mesic meadow region has slightly declined over time and has relatively low NDVI values that signal stressed or sparse vegetation.

Spooner Meadow SEZ Baseline Condition Assessment Ratings

The TRPA Lake Tahoe Basin Stream Environment Zone (SEZ) Baseline Condition Assessment was designed to provide a comprehensive baseline assessment of streams, meadows, riparian areas, and other wetlands and waters in the Lake Tahoe Basin (TRPA 2020). Spooner Meadow and North Canyon Creek were evaluated as several separate SEZ areas (online map viewer: https://gis.trpa.org/tahoesezviewer/). The channeled portion of Spooner Meadow that spans the southern region (Spooner meadows-1) received an overall ‘A’ rating. This area of the meadow includes the section of North Canyon Creek that joins with the drainage from Spooner Lake and flows through the meadow towards Highway 28. No indications of degradation were noted. However, it received a ‘C’ rating for biotic integrity and a ‘B’ rating for habitat fragmentation. The channeled portion of Spooner Meadow located on the eastern side along North Canyon Road (Spooner meadows-2) received an overall ‘B’ rating. This portion of the meadow includes a section of North Canyon Creek upstream of Spooner Lake that supports riparian vegetation. The creek was noted as being stable but deeply incised and ditched. Sagebrush encroachment was noted in the upper reach of the meadow. This region of Spooner Meadow was given a ‘C’ rating for aquatic organism passage, a ‘B’ for conifer encroachment, and a ‘D’ for incision. The two non-channeled regions of the meadow both received overall ‘A’ ratings. However, the non-channeled region centrally located in mesic meadow (Spooner meadows-5) received a ‘B’ rating for conifer encroachment. The non-channeled region on the west side of the meadow (Spooner meadows-3) had no indicators of degradation, although a little conifer encroachment was noted and it received a ‘B’ rating for headcuts.

RECOMMENDATIONS

A Scoring System for Assessing Spooner Meadow Condition

Several quantitative vegetation, soil, and water quality measurements related to indicators used in the SEZ Baseline Condition Assessment could be used as metrics to create a scoring system for assessing Spooner Meadow health.

For example, primary productivity, habitat, biodiversity, and encroachment could be assessed via vegetation metrics related to several SEZ Indicators:

Vegetation Metric 1: Aboveground Biomass

Measurements of AGBM collected from sample plots (whether from the same Study Plots used for this project or from new plots) could be used to rate primary productivity across the meadow. This metric would relate to SEZ Indicator 2 (Vegetation Vigor) and complement NDVI analysis already used in SEZ assessments.

For example, AGBM could be scored as:

- > 400 g m^{-2} = 4
- 301-400 g m^{-2} = 3
- 201-300 g m^{-2} = 2
- 100-200 g m^{-2} = 1
- < 100 g m^{-2} = 0

This break down of AGBM ranges is based on AGBM values reported for montane meadows in the Sierra Nevada and elsewhere in the US (Table 3). Based on results from this study (Figure 9), Study Plots would score as follows:

- Plot 1 = 4 in 2023, 0 in 2024
- Plot 2 = 3 in 2023, 1 in 2024
- Plot 3 = 3 in 2023, 1 in 2024
- Plot 4 = 4 in 2023 and 2024
- Plot 5 = 4 in 2023 and 2024

The average scores are 3.6 in 2023 and 2 in 2024, suggesting reduced meadow health. (As determined in this study, ABGM values in 2024 could be the result of inconsistent field sampling and not necessarily indicative of poor primary productivity. This points to an important consideration for any scoring system: scores should be interpreted in context of sampling conditions that might artificially inflate or deflate scores.)

Vegetation Metric 2: Percent Vegetation Cover

Measurements of percent vegetation cover measured in sample plots could be used to evaluate total vegetation cover across the meadow and identify bare or patchy areas indicative of disturbance. Percent cover could also be broken down by type or species, as in this study, to measure extents of native vs. non-native invasive species or meadow vs. upland species. This metric would relate to SEZ Indicators 2 and 9 (Invasive Plant Species).

For example, total vegetation cover could be scored as:

- > 70% cover = 4
- 51-70% = 3
- 31-50% = 2
- 11-30% = 1
- 0-10% = 0

Based on this study, the Study Plots would receive the following scores based on percent cover measurements for 2023 and 2024 combined (Figure 14):

- Plot 1 = 4
- Plot 2 = 4
- Plot 3 = 2
- Plot 4 = 3
- Plot 5 = 4

The average score for total vegetation cover is 3.4, which may indicate a healthy level of vegetation vigor. To relate the percent cover metric to SEZ Indicator 9, similar scoring could be applied to percent cover by species.

Vegetation Metric 3: Plant Biodiversity

Measurements of plant species density from sample plots could be used to rate species richness and overall plant biodiversity, based on values calculated for Shannon's Diversity Index, Margalef's Richness Index, and/or Pielou's Evenness Index. This metric would relate to SEZ Indicators 2 and 9. It could also complement SEZ Indicator 8 (Biotic Integrity), which evaluates the composition of aquatic organisms.

For example, plant biodiversity could be scored as follows using Shannon's Diversity Index (H):

- > 3 = 3
- > 2-3 = 2
- > 1-2 = 1
- 0-1 = 0

Using results from this study (Table 4), Study Plots would rate as follows:

- Plot 1 = 1
- Plot 2 = 2

- Plot 3 = 0
- Plot 4 = 0
- Plot 5 = 1

The average score for biodiversity is 0.8, suggesting low biodiversity in the meadow. However, further work is needed to identify H values typical of montane meadows and determine what values in montane meadows indicate “high” vs. “low” biodiversity.

Vegetation Metric 4: Conifer Encroachment

A combination of remote sensing analysis and field-based measurements of tree counts could be used to support SEZ Indicator 7 (Conifer Encroachment). Increased tree cover observed in Spooner Meadow via remote sensing analysis (Figure 21) cannot clearly be attributed to conifer encroachment. It is more likely due to increased willow density along North Canyon Creek. However, annual trends from remote sensing could be used in combination with field counts of different life stages of lodgepole pine (seedlings, saplings, adults) sampled along transects, similar to the shrub encroachment study conducted by TMCC students (Figure 20). More research is needed to determine an appropriate scoring system for this metric, which could be based on overall percent lodgepole pine cover within the meadow, or on counts/densities of trees.

In addition to vegetation metrics, metrics for soil characteristics could be developed to relate to SEZ Indicators, such as:

Soil Metric 1: Soil Moisture

Soil moisture measurements from installed soil sensors or measured from collected soil samples could be used to evaluate the effects of ditches and other water diversions on hydrologic connectivity through the meadow. This metric would relate to SEZ Indicator 4 (Ditches/Gullies).

For example, soil moisture values during spring snowmelt (using VWC) could be scored as:

- > 50 % = 4
- 36-50% = 3
- 21-35% = 2
- 11-20% = 1
- 0-10% = 0

Using soil measurements from this study (Figure 7; averaged across depths) in 2024 and 2025, Study Plots would score as follows:

- Plot 1 = 4 in 2024 and 2025
- Plot 2 = 4 in 2024 and 3 in 2025
- Plot 3 = 1 in 2024 and 2 in 2025
- Plot 4 = 4 in 2024 and 2025
- Plot 5 = NA in 2024 and 3 2025

The average score for soil moisture is 3.25 in 2024 and 3.2 in 2025. Repeated scoring over time would inform whether hydrologic connectivity in the meadow is increasing or decreasing.

Additionally, metrics for water quality could be used to evaluate the health of North Canyon Creek and its function in providing habitat for aquatic organisms as well as to assess the role Spooner

Meadow plays in benefitting water quality of the creek before it reaches Lake Tahoe. Such metrics would relate to SEZ Indicators 8 (Biotic Integrity) and 10 (Aquatic Organism Passage).

Water Quality Metric 1: Dissolved Oxygen

Dissolved oxygen could be measured on a regular basis at specific positions along North Canyon Creek, similar to those used in this study, or at positions along the to-be restored section of creek. Because DO directly affects habitat quality for aquatic organisms, this metric would relate to SEZ Indicators 8 and 10.

For example, DO values could be scored as follows, with the threshold for the lowest rating being the TRPA DO standard of 6 mg L^{-1} (TRPA 2007):

- > 10 mg L^{-1} = 3
- 8-10 L^{-1} = 2
- 6-8 mg L^{-1} = 1
- 0-6 mg L^{-1} = 0

Based on DO values measuring during the growing season (June-September, when DO is more likely to be low) in this study (Figure 24), North Canyon Creek sampling locations would receive the following scores:

- Upstream = 3
- Culvert = 1
- Meadow Center = 1
- Downstream = 2

The average score for the DO metric is 1.75, which would suggest that DO may not be high enough to support diverse aquatic life and should be evaluated in the context of high iron concentrations occurring in North Canyon Creek (NDEP 2022).

Water Quality Metric 2: Conductivity

Similarly, conductivity could be measured on a regular basis at specific positions along North Canyon Creek to monitor ion concentration.

For example, conductivity could be scored as follows, using 10 μS cm^{-1} as a threshold for ideal conductivity levels for waters flowing into Lake Tahoe (Vidra 2015) and 500 μS cm^{-1} as the threshold for the lowest conductivity rating, per APHA (1992):

- ≤ 10 μS cm^{-1} = 3
- 11-400 μS cm^{-1} = 2
- 401-500 μS cm^{-1} = 1
- > 500 μS cm^{-1} = 0

Based on conductivity values measured during the growing season in this study (Figure 25), North Canyon Creek sampling locations would receive the following scores:

- Upstream = 2
- Culvert = 1
- Meadow Center = 2

- Downstream = 2

The average score for the conductivity metric is 1.75. Whether the range of values presented here to score conductivity is realistic requires the expertise of a water quality specialist.

Water Quality Metric 3: Total Dissolved Solids

A metric for TDS could also be measured on a regular basis at specific positions along North Canyon Creek.

For example, TDS could be scored to incorporate the Nevada standard of 500 mg L^{-1} and the Lake Tahoe standard of 70 mg L^{-1} (Vidra 2015):

- $\leq$ 70 mg L^{-1} = 3
- 71-90 mg L^{-1} = 2
- 91-499 mg L^{-1} = 1
- > 500 mg L^{-1} = 0

Based on TDS measured during the growing season in this study (Figure 25), North Canyon Creek sampling locations would receive the following scores:

- Upstream = 2
- Culvert = 1
- Meadow Center = 1
- Downstream = 1

The average score for the TDS metric is 1, which could indicate that TDS is at a healthy level, somewhere between the Nevada standard and Lake Tahoe standard. As with the other water quality metrics presented here, a water quality expert should be consulted to determine appropriate ranges for scoring TDS.

Other metrics that are not included here should also be considered, such as metrics relating to wildlife and insect biodiversity, the physical condition of North Canyon Creek, and other water quality measurements (such as total suspended solids and turbidity).

All of the metric scores could be combined to calculate an overall meadow score. Meadow scores could be compared between years to determine a temporal trajectory of meadow health (i.e., whether meadow health is improving or declining over time) and identify factors (e.g., restoration, environmental conditions, land use changes) that influence the trajectory. Please note that the proposed metrics above are provided merely as examples. Input from resource managers, biologists, hydrologists, and other experts is needed to develop an effective and robust scoring system for Spooner Meadow.

CRAM

Meadow condition could also be assessed using the California Rapid Assessment Method for Wetlands (CRAM) (CWMW 2013). This method involves evaluating four attributes (landscape context and buffer, hydrology, physical structure, and biotic structure), calculating scores for each attribute based on various metrics, and generating an overall score. It is intended to be a rapid, reproducible evaluation that uses quantitative and qualitative measures of wetland and watershed condition. Although CRAM was designed for California wetlands, Spooner Meadow is not distinctly different from montane meadows on the California side of the Lake Tahoe Basin, where CRAM has been used and to which Spooner Meadow scores could be compared. Spooner Meadow is considered a Slope Wetland type under CRAM. Similar to the Lake Tahoe Basin SEZ Condition Assessment Method, CRAM classifies meadows as channeled and non-channeled meadows. CRAM assessments would need to be conducted by someone trained in using CRAM for slope wetlands. CRAM could be used to supplement a scoring system tailored for Spooner Meadow or as a resource for developing a scoring system that also relates to the SEZ Condition Assessment Method.

Post-Restoration Monitoring

Following restoration activities, we recommend post-restoration monitoring of Spooner Meadow and North Canyon Creek to evaluate restoration success and capture restoration effects on the ecological health of Spooner Meadow. Monitoring the same vegetation, soil, and water quality characteristics evaluated in this study would allow direct comparison of meadow condition before and after restoration. However, it may be necessary to modify the study design to collect additional or different data to best measure restoration success. Conducting an assessment of the meadow (such as a Spooner Meadow-specific scoring system described above or CRAM) would also be valuable for determining overall meadow condition and identifying specific management actions that would benefit ecological functions and the long-term health of Spooner Meadow.

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APPENDICES

A: List of Plant Species Observed in Spooner Meadow

Family	Species	Common Name	Presence[a]						Status[b]
			P1	P2	P3	P4	P5	M	
Apiaceae	*Perideridia parishii*	Parish's yampah	1	1				X	N
Asteraceae	*Arnica chamissonis*	chamisso arnica	X	X				X	N
Asteraceae	*Achillea millefolium*	yarrow	1	X				X	N
Asteraceae	*Agoseris glauca*	pale false dandelion	X	X				X	N
Asteraceae	*Symphyotrichum spathulatum*	western mountain aster	1	1				X	N
Asteraceae	*Taraxacum officinale*	common dandelion	1	1				X	X
Asteraceae	*Unknown species*	N/A				1		X	?
Caryophyllaceae	*Stellaria longipes*	long-stalked starwort		1		1		X	N
Cyperaceae	*Carex aquatilis*	water sedge				X	X	X	N
Cyperaceae	*Carex athrostachya*	slender beak sedge					X	X	N
Cyperaceae	*Carex nebrascensis*	Nebraska sedge	1	1		1	1	X	N
Cyperaceae	*Carex utriculate*	beaked sedge					1	X	N
Cyperaceae	*Carex* spp.	sedges	X	X	1	X	X	X	N
Cyperaceae	*Scirpus microcarpus*	small-fruited bulrush						X	N
Fabaceae	*Trifolium longipes*	long-stalked clover	1	1	1			X	N
Fabaceae	*Trifolium* sp.	clover		X				X	?
Juncaceae	*Juncus balticus*	Baltic rush	1	1	1	1	1	X	N
Juncaceae	*Juncus* spp.	rushes	X	X	X	X		X	N
Lemnaceae	*Lemna* sp.	duckweed					X	X	N
Malvaceae	*Sidalcea oregana*	Oregon checker mallow						X	N
Onagraceae	*Gayophytum diffusum*	spreading groundsmoke			1			X	N
Onagraceae	*Epilobium ciliatum*	willowherb					1	X	N
Orchidaceae	*Platanthera dilatata*	Sierra bog orchid						X	N
Orobanchaceae	*Castilleja miniata*	scarlet paintbrush					1	X	N
Phrymaceae	*Erythranthe primuloides*	primrose monkeyflower						X	N
Plantaginaceae	*Collinsia parviflora*	blue-eyed Mary		1		1		X	N
Plantaginaceae	*Penstemon rydbergii*	Rydberg's penstemon	1	1	X			X	N
Plantaginaceae	*Veronica americana*	American brooklime					1	X	N
Poaceae	*Agrostis* sp.	bentgrass						X	?
Poaceae	*Bromus* sp.	brome	1					X	X
Poaceae	*Calamagrostis stricta*	narrow-spiked reedgrass						X	N
Poaceae	*Deschampsia caespitosa*	tufted hairgrass	1	1	1	1	1	X	N
Poaceae	*Muhlenbergia richardsonis*	mat muhly			1			X	N
Poaceae	*Poa* spp.	blue grass	1	1	1			X	?
Poaceae	Unknown species	grasses	X	X	X	1	1	X	?
Polemoniaceae	*Phlox gracilis*	slender phlox						X	N
Polygonaceae	*Bistorta bistortoides*	American bistort	X					X	N

Polygonaceae	*Rumex acetosella*	sheep sorrel						X	X
Primulaceae	*Dodecatheon alpinum*	alpine shooting star						X	N
Ranunculaceae	*Ranunculus alismifolius*	plantainleaf buttercup	1	1				X	N
Rosaceae	*Geum macrophyllum*	large-leaved avens				1	1	X	N
Rosaceae	*Potentilla gracilis*	Slender cinquefoil		1				X	N
Rubiaceae	*Galium* sp.	Bedstraw					1	X	N
Salicaceae	*Salix exigua*	Narrowleaf willow						X	N
Salicaceae	*Salix geyeriana*	Geyer's willow						X	N
Salicaceae	*Salix lemmonii*	Lemmon's willow						X	N
Scrophulariaceae	*Limosella* sp.	Mudwort					1	X	N
Unknown forbs			X	X	X	X	1	X	N

[a]Study Plots where species was observed, or if the species was observed elsewhere in the meadow, it is marked in the meadow column ('M'). '1' indicates the species was captured in quadrat sampling. 'X' indicates the species was not captured in quadrat sampling but was observed in the plot.

[b]Status refers to whether a species is native (N), non-native (X), invasive (I), or status is unknown (?).

B: Spooner Meadow Project Photos


Photo 1. North Canyon Creek flowing through Spooner Meadow.


Photo 2. North Canyon Creek flowing through Spooner Meadow.

Photo 3. Study Plot 1 during a wildflower bloom of plantainleaf buttercup (*Ranunculus alismifolius*) in June 2023, before the soil sensor was installed.

Photo 4. Study Plot 1 in June 2025.

Photo 5. Study Plot 2 in June 2023 before soil sensor was installed.

Photo 6. Study Plot 2 in June 2025.

Photo 7. Study Plot 3 in June 2023 before soil sensor was installed.

Photo 8. Study Plot 3 in May 2025.

Photo 9. Study Plot 4 in June 2023 showing tributary of North Canyon Creek that runs along edge of plot.

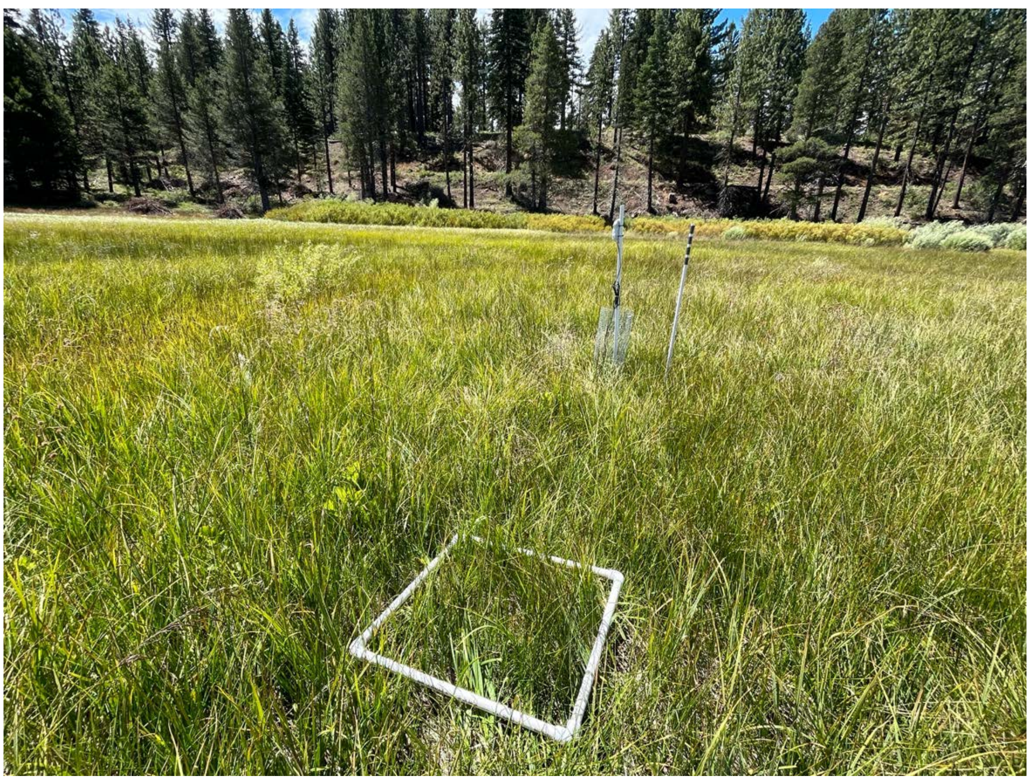
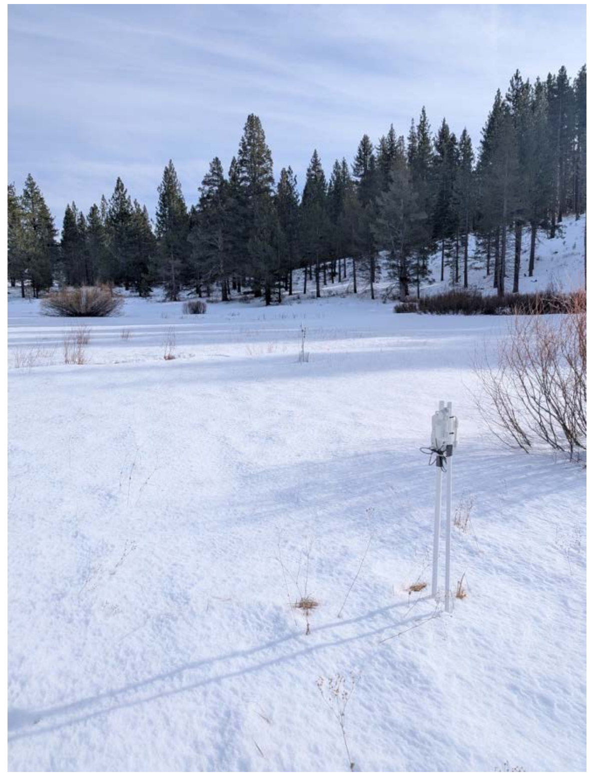


Photo 10. Study Plot 4 during vegetation sampling in Summer 2023.

Photo 11. Study Plot 5 in June 2023 before soil sensor was installed.

Photo 12. Study Plot 5 in February 2024 with patchy snow.

Photos 13 and 14. Snowpack at Study Plots 1 and 2 in December 2024.


Photos 15 and 16. Snowpack at Study Plots 3 and 4 in December 2024.

Photo 17. Snowpack at Study Plot 5 in December 2024.

Photo 18. Snowpack across Spooner Meadow in February 2024.


Photo 19. Upstream water quality sampling location in September 2024.


Photo 20. View of Spooner Meadow from the Culvert water quality sampling location in July 2024.

Photo 21. Meadow Center water quality sampling location in April 2025.

Photo 22. Downstream water quality sampling location, near a water gauge in April 2025.


Photo 23. UNR Student Research Assistant, Abbey Albion, doing fieldwork in 2024.


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Photo 24. UNR Student Research Assistant, Devon Ardesco, doing fieldwork in 2024.

Photo 25. TMCC student research assistants (Grant Blattman, Ryan Carlson, Cynthia Ramos Nunez, and Lizzie Thornton) collecting data on shrub encroachment in Fall 2023.

Photo 26. TMCC Student Research Assistants collecting data on shrub encroachment in Fall 2023.

Photo 27. Litterbag collected from Study Plot 3.

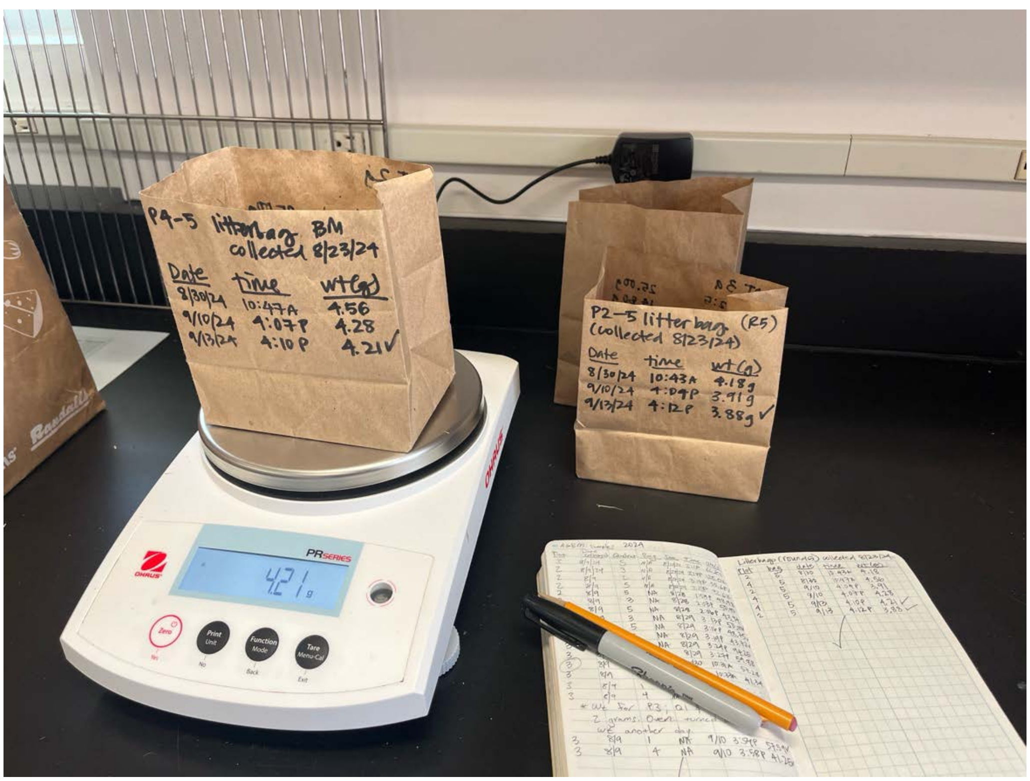

Photo 28. Weighing plant material collected from litter bags in 2024.