



Quantifying multiple ecosystem service responses to adaptive multi-paddock grazing management in a north American semi-arid sagebrush steppe ranch experiment

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Abstract

The provisioning of ecosystem services (Food & Fiber, Water, Carbon, Biodiversity, Wildlife) by rangelands used for livestock production is critical for social and ecological sustainability globally. Adaptive management through adjustments to grazing intensity, timing, and duration are of increasing interest to optimize multiple ecosystem services with increasing pressures from climate change and other environmental stressors. Yet, there is a need for more empirical grazing research at ranch-scales that quantifies management impacts on the suite of ecosystem services. In 2023, we established a ranch-scale experiment (943 ha) in a semi-arid sagebrush steppe rangeland in Wyoming, USA with grazing treatments stratified by ecological sites. Specifically, we established pairs of pastures (ranging in size from 39 to 149 ha) on five soil types: Saline Loamy, Clayey, Loamy, Sandy, and Shallow Loamy soils. Grazing was in the summer. Treatments included 5 Prescriptive (PR) herds grazed continuously for 11 weeks (ranging in size from 10 to 31 cow-calf pairs depending on pasture size; 100 cow-calf pairs total) and 1 Adaptive (AD) herd (100 cow-calf pairs) rotating through 5 pastures every 0.5 to 3 weeks based on adaptive decision making relative to animal behaviour, forage utilization, and weather. Grazing treatments had the same planned system-level stocking rate (meaning a similar number of cow-calf pairs for similar total treatment areas) but were managed with a different stock density -- with the higher density in the AD treatment with potentially different duration. We concurrently sampled multiple ecosystem services at the pasture scale including soil moisture and carbon, forage biomass and quality, wildlife habitat and populations (native rodents, predators, ungulates, and birds), cattle (movement and productivity), and CO₂ fluxes. We present data from the 2023 and 2024 seasons for the suite of ecosystem services with implications for the refinement of adaptive grazing management and intensification in semi-arid sagebrush steppe.

Introduction

Rangelands have the ability to provision a suite of ecosystem services simultaneously, broadly including food & fiber, water, carbon, biodiversity, and wildlife (Goodwin and Porensky 2023). From a multifunctional landscape

perspective, rangelands sustainably managed may accomplish this provisioning of multiple ecosystem services through supporting livestock production which is critical for social and ecological sustainability globally (Godde et al. 2020; Monlezun et al. 2024). Yet, quantifying the full suite of ecosystem services presents a challenge in terms of sampling, instrumentation, cost, and infrastructure. Moreover, empirical approaches to understanding how manager decision making influences multiple ecosystem services simultaneously, and relevant tradeoffs, returns on investment (ROI), and temporal trajectories for improvement, remain limited. Given the threats of climate change, urbanization, desertification, and other threats to the people, flora, and fauna on rangelands, enhanced sampling is a critical and emerging need. Concurrent with the need to enhance broad sampling of rangeland ecosystem services has been the emergence in the interest about adaptive grazing management. Adaptive management through adjustments to grazing intensity, timing, and duration are of increasing interest to optimize multiple ecosystem services with increasing pressures from climate change and other environmental stressors. There have been variable claims about the singular benefits of such adaptive grazing management (Briske et al. 2008; Mosier et al. 2021; Jorns et al. 2024); therefore there is a need for more empirical grazing research at ranch-scales that quantifies impacts of adaptive management on multiple ecosystem services. Here we describe a new experiment quantifying multiple ecosystem service responses to adaptive multi-paddock grazing management in a North American semi-arid sagebrush steppe ranch experiment which will have implications for western North America but also arid and semi-arid rangelands globally.

Methods

The study site is managed by the University of Wyoming's (UW) Agricultural Experiment Station (AES) – Laramie Research and Extension Center (LREC) and is known as the McGuire Ranch (latitude 41° 41' 11.54" N, longitude 105° 33' 24.09" W). The ranch is located in Albany County, Wyoming, USA on the west side of the Laramie mountain range and on the east side of the Snowy Mountain Range and is in the Deserts and Xeric Shrublands Ecoregion according to the The Nature Conservancy classification and more specifically, is in the Wyoming Basin (18) Level III Environmental Protection Agency (EPA) Ecoregion which is a broad arid intermontane basin characterized by grasslands and shrublands. The climate is an arid cold steppe (BSk according to the Köppen classification) due to it being temperate, continental, with winter snow, and having a broad thermal gradient. The cold climate is, in part, associated with the high altitudinal position which is 2,190 m above sea level. Annual rainfall averages from 230 to 467 mm yr⁻¹ with an average of 353 ± 14 (SE) mm yr⁻¹ since 2000. Average annual air temperature since 2000 was 5.4 °C. Average air temperature ranges from -5.5 °C (winter) to 17.2 °C (summer), with mean minimum and maximum temperature of -1.3 °C and 12.2 °C, respectively. The McGuire Ranch is an area of 2,246 ha that is dominated by cool-season perennial grasses and sagebrush (*Artemisia* species) shrubs. The ranch was acquired by UW in 1992 and has been managed in a 3 or 4 pasture system since then for summer seasonal grazing (June through October) of cow-calf pairs. In 2022, 19 km of new internal fence [4-strand wildlife friendly for pronghorn (*Antilocapra americana*) and mule deer (*Odocoileus hemionus*)] and 3 new water tanks (1 – 9 m diameter tank providing water to 4 pastures and 2 – 15' diameter tanks providing water to 2 pastures each) taking the ranch to 14 pastures. This ranch is considered a semi-arid sagebrush steppe ecosystem and is a predominantly native rangeland co-dominated by grasses and shrubs with no trees. The dominant native cool-season grass species include muttongrass (*Poa fendleriana* (Steud.) Vasey), prairie Junegrass (*Koeleria macrantha* (Ledeb.) Schult.), and western wheatgrass (*Pascopyrum smithii* (Rydb.) Å. Löve). In a few study pastures (n = 4) with a history of tillage there are a few non-native cool-season grass species including crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), meadow brome (*Bromus biebersteinii* Roem. & Schult.), and Russian wildrye (*Psathyrostachys juncea* (Fisch.) Nevski). The dominant shrub species include Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) and yellow rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.). We established a ranch-scale experiment using approximately 42% of the ranch (943 ha) with grazing treatments stratified by ecological sites in 2023. In order to understand the role of soil texture and ecological site responses to management, we established pairs of pastures (ranging in size from 39 to 149 ha) on five ecological sites with variable soils including saline loamy, clayey, loamy, sandy, and shallow loamy soils. We applied grazing in the growing season due to the severe winters in this area which renders winter grazing practically impossible.

Grazing treatments included 5 Prescriptive (PR) herds grazed continuously for 11 weeks (ranging in size from 10 to 31 cow-calf pairs depending on pasture size; 100 cow-calf pairs total) and 1 Adaptive (AD) herd (100 cow-calf pairs) rotating through 5 pastures every 0.5 to 3 weeks based on adaptive decision making relative to animal behaviour, forage utilization (50% target based on Wyoming Rangeland Monitoring Guide using the Landscape Appearance method), and weather (Figure 1). Grazing treatments had the same planned system-level stocking rate (meaning a similar number of cow-calf pairs for similar total treatment areas) but were managed with a different stock density -- with the higher density in the AD treatment with potentially different duration.

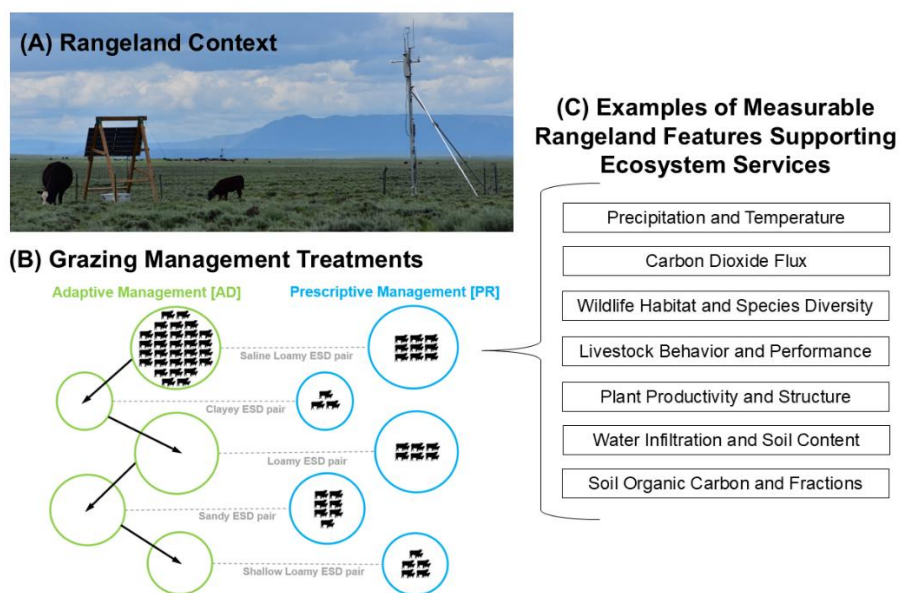


Figure 1. (A) Rangeland context, (B) Grazing management treatments with pastures represented by circles and treatments stratified by soils and ecological site descriptions (ESDs), and (C) measured rangeland features supporting a suite of ecosystem services on the McGuire Ranch in southeastern Wyoming, USA.

We implemented a suite of sampling at the pasture scale. Soils are sampled in each pasture using 12 triangles using a truck-mounted Giddings probe down to 1 m (if possible) with cores cut and sub-sampled at 4 depths: 0-15 cm, 15-30 cm, 30-50 cm, and 50-100 cm. Soil samples were cooled and sent to the laboratory for measurement of SOC/N, isotopes, SOC fractions (chAOM, lPOM, MAOM), BD, pH, texture, IC, and WSA. Soil moisture is being measured using SATURO infiltrometers with three samples per pasture with 10 cm rings to 10 cm depth to assess saturated hydraulic conductivity. In addition, in each pasture volumetric soil water content is being measured at three locations at 10 cm, 20 cm, and 30 cm depths using TEROS 10 (METER Group) capacitance sensor. Weather and greenhouse gas flux, specifically CO₂, is measured with solar powered flux towers that include a 3D sonic anemometer, a four component net radiometer, an ambient air temperature/humidity/pressure and rain sensor and an enclosure for trace gas measurements, soil heat flux plate, and soil temperature/moisture sensor (at 10 to 15 cm depth) provided by Quanterra Systems. Importantly, flux towers enable calculation of F_c, LE, H, based on EC technique. Forage biomass is sampled every 28 days during the growing season months of May, June, July, and August using 3 – 100 m transects with 2 – 0.5 m² quadrats clipped to ground level per transect. In addition, standing biomass is also measured every 10 m on the same transects using the non-destructive visual obstruction reading (VOR) technique modified but generally following Robel et al. (1970) where an observer observes a pole with 1 cm increment markings from a height of 1m and a distance of 4 m and records the plant species obstructing the lowest interval on the pole not completely obstructed as well as the highest interval where there was any obstruction. Forage samples will be assessed for forage quality metrics such as crude protein, energy, and digestibility. We are also using Ecological Outcome Verification (EOV) methods to assess water

cycling, mineral cycling, energy flow, and community dynamics (Savory Institute 2024). Livestock variables measured included foraging behaviour using standardized observation techniques, animal movement using GPS-ear tags, and performance using calf weaning weights (to be initiated in 2025). In addition, grazing management data such as animal days per acre are also calculated. Wildlife are being measured using a network of infrared game cameras with a particular interest for large ungulates and carnivores. Bird communities are being measured using point count methods and in 2024 nest survival was being measured with nest searching techniques – and both techniques included additional habitat metrics being measured.

Results

Grazing treatments have been applied in 2023 and 2024 which were very different in terms of weather with 2023 being wetter through the growing season and 2024 drier early with late summer rains. The implementation of such a sampling system has been challenging the least. Cow days per acre have been higher in the AD treatment than the PR treatment both years (17% and 27% respectively) suggesting the realization of grazing management treatment different. We are in the process of integrating and summarizing our ecosystem service related data. Additional results at this point include lessons learned for establishing such networks in working rangeland landscapes. First, a diverse team of experts is required, and in our case, includes more than 40 individuals. Second, installation of such instrumentation takes time and financial resources that has to include trouble shooting and repair. Third, the streams of data will require dedicated personnel to build platforms that integrate and scaffold data into a useable interface. Fourth, measuring the response of the suite of ecosystem service responses will take time and likely 3 to 5 years.

Discussion

We are concurrently sampling multiple ecosystem services at the pasture scale including soil moisture and carbon, forage biomass and quality, wildlife habitat and populations (native rodents, predators, ungulates, and birds), cattle (movement and productivity), and CO₂ fluxes in a project that is the first of its kind in terms of scope. This adaptive multi-paddock grazing management in a North American semi-arid sagebrush steppe ranch experiment will have implications for western North America but also arid and semi-arid rangelands globally.

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