Interactive Effects of Soil and Browsing on Big Sagebrush: Implications for Restoration Success

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INTERACTIVE EFFECTS OF SOIL AND BROWSING ON BIG SAGEBRUSH:
IMPLICATIONS FOR RESTORATION SUCCESS

by

Kyle C. Nehring

A thesis submitted in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Ecology

Approved:

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2021
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My work and training as an ecologist has been quite the journey over eight years. I started as a Master’s student, ready to get off of my ATV in the bitter Wyoming Winters and challenge my skills as a scientist to move from field technician to academic. In my time at USU, my advisor, committee, and cohort made me realize that I could do more and I decided to pursue the elusive PhD. However, my body had other ideas. After working to come to terms with my ego and letting go of the vast analyzed field studies and databases that I have created, I am finally at the finish line with a Master’s degree.

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“And now for something completely different…”

- Monty Python
PROJECT OUTLINE

Interactive Effects of Soils and Browsing on Big Sagebrush:
Implications for Restoration Success

by

Kyle C. Nehring, Master of Science
Utah State University, 2021

Major Professor: Dr. Kari E. Veblen
Department: Wildland Resources

INTRODUCTION / NEED

Background information and previous work

Sagebrush-dominated plant communities provide critical wildlife habitat for ungulates (e.g., mule deer) and sensitive species (e.g., sage-grouse). Moisture stress increases plant mortality and can reduce cover of big sagebrush (A. tridentata), the foundational species in sagebrush habitat. Sagebrush plants primarily use water from upper soil layers for growth and from deep soil layers for physiological maintenance and survival in dry seasons (Ryel et al. 2002, Germino and Reinhardt 2014). Therefore, a critical time period for sagebrush is late spring/early summer (following winter/spring recharge of the soil profile) when shallow soil layers have dried and individuals must rely on deeper soil reserves (Schlaepfer et al. 2012b).

The effects of atmospheric precipitation on sagebrush stress and survival are mediated by soil texture. Finer textured soils have greater water holding capacity than
coarser textured soils; therefore finer textured soils effectively create a larger reservoir of available water for the same volume of soil (Austin et al. 2004). However, evaporative water loss from upper soil layers can be greater in fine-textured vs. coarse-textured soil, thereby decreasing sagebrush use of summer water pulses and decreasing its active growing season (Austin et al. 2004, Schlaepfer et al. 2012a). Further, fine-textured upper soil layers may increase productivity of more shallow rooted species such as forbs and grasses, thereby increasing competition with sagebrush for scarce water resources. In contrast, sandy soil surfaces dry out quickly, and effectively act as a mulch to minimize subsequent water loss by evaporation.

The degree to which soil depth affects the stress and survival of *A. tridentata* depends on atmospheric precipitation. It is well established that sagebrush growing in shallow soils do not have access to deep soil moisture during dry summer months and have a higher risk of death from root apoxia when soils are too wet (Germino and Reinhardt 2014). However, *A. tridentata* plants in these shallow soils also tend to demonstrate higher water use efficiency (WUE), which is advantageous in drought conditions (Schlaepfer et al. 2012b, Germino and Reinhardt 2014). While it is generally perceived that deep soils provide a larger reservoir of water potentially available to plants, shallow soils may be especially advantageous when soils are sandy and excessively well-drained, such as in lower elevation dry margins of sagebrush distribution on the Colorado Plateau. In these landscapes, water infiltration and downward percolation are rapid, and bedrock or other water- and root-restricting layers help retain soil water in the root zone and available for plant uptake. Our preliminary data from this region show that, over the long term,
sagebrush persist primarily where a water-restricting layer occurs within the upper 100cm of soil (Fig. 1).

![Figure 1](image.png)

**Figure 1.** Total densities of live sagebrush in deep (Greater than 100cm deep) vs. moderately deep soils (Less than 100cm)

Plant responses to herbivory vary across the landscape, usually attributed to variation in soils, topography, and rainfall (e.g., Browning et al. 2012, Augustine and Derner 2014). Selective removal of plant tissue by herbivores can reduce plant survival, growth, reproduction and competitive ability (Bullock 1991, Augustine and McNaughton 1998). Under moisture stress plants can be even worse equipped to deal with herbivory. Our pilot study data suggest a strong role of soil properties in mediating browsing effects on sagebrush plants. Our preliminary data suggest that suppressive effects of wildlife browsing on sagebrush densities are much more dramatic in deeper soils than in shallower soils (Fig. 2). This is likely due to an herbivory-soil ecohydrologic interaction.
Sagebrush must rely on sub-soil reserves of water during late spring/early summer when near-surface soil layers have dried. Sagebrush growing on soils with a lithic or similar water-limiting layer within the rooting zone may have improved water relations and therefore be more resilient to animal browsing, which may be especially important in coarse-textured soils.

**Wyoming Big Sagebrush**

![Graph showing shrub densities in shallow vs. deep soils.](image)

**Figure 2.** Total shrub densities in shallow vs. deep soils. “TOT” excludes ungulate browsers while “LX” allows wild ungulate browsers. LX plots reduced shrub densities (relative to TOT) far more in deep than shallow sites. Data are from 14 sites in the Colorado Plateau, Southeastern Utah.

Negative effects of animal browsing on sagebrush may be further reinforced via **feedbacks with plant defenses.** Moisture stress can negatively impact concentrations of defense chemicals that sagebrush produce to deter herbivory (Yuan et al. 2009). By altering the availability of water and nutrient resources, soil texture and depth also can then further influence production of defense chemicals. Powell (1970) found that sagebrush growing in
coarser textured soils can have greater volatile oil levels than sagebrush in finer textured soils. However, there have been no further studies on the consequences of varying soil properties for sagebrush herbivore defenses (and feedbacks onto plant survival).

**Problem statement and proposed need**

Heterogeneity in landscape conditions (e.g., soil types) precludes a “one size fits all” management strategy across large landscapes. New management approaches that explicitly account for heterogeneous landscapes (and the variable conditions therein) will be required to maintain habitat quality. In particular, we require an improved **mechanistic understanding** of how the **outcomes of conservation and restoration** actions are contingent upon a) **contextual abiotic factors** (e.g., moisture availability mediated by soils and precipitation) and b) their **interactions with biotic factors** (e.g., browsing wildlife).

We propose to answer fundamental questions about how big sagebrush (*Artemisia tridentata*), the foundational species for sagebrush habitat, responds to browsing over a variety of soil moisture conditions. Ultimately, this work will lend insight into how **soils and herbivory influence persistence of sagebrush** over heterogeneous landscapes, and ultimately contribute to maintenance of habitat for wildlife. This information can then be used to create decision support tools to help **prioritize conservation and restoration actions across broad landscapes**, targeting areas where management actions are most needed and/or likely to be successful. Ultimately this work will improve managers’ ability to **maintain wildlife habitat**.
OBJECTIVES AND GOALS

Although soil factors and drought can synergistically influence soil water availability, no research has addressed how browsing interacts with these factors to influence sagebrush stress, growth and survival, and ultimately, the potential success of conservation and restoration efforts.

Therefore, the objectives of this proposal are to:

1) Perform a controlled experiment on soil types found in Beef Basin and surrounding areas that specifically examines the roles of soil depth, soil texture, and herbivory on sagebrush stress, survival and reproduction.

2) Use information from Objective 1 to create soil-based decision support tools that can be used to identify areas with the highest probability of restoration success.

METHODS / APPROACH

Objective 1

We will perform a replicated experiment that tests for interactive effects of browsing, soil depth, and soil texture on big sagebrush (A. tridentata) plants. Our proposed study sites are located in San Juan County, in southeastern Utah. The dominant vegetation is Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis) shrubs, with grass and forb understories. This region is at the drier periphery of sagebrush distribution (~250mm annual rainfall) where sagebrush is expected to be most vulnerable to drought. Our seedling study (part 1) will be located in the “Beef Basin” area (~3,700 ha) that has experienced sagebrush die-offs over the last several decades; plots will be located in sites with residual sagebrush where the understory is dominated by low cover of
perennial grasses, such as *Bouteloua gracilis*. **Our seedling study (part 2)** and the **adult plant portion of our study** will be located in similar soil types as the seedling study, but in the “Hart’s Draw/Hart’s Point”, “Black Mesa” and “Alkali” areas where historic management has resulted in relatively intact sagebrush stands, but where restoration actions are ongoing. Experimental plots are distributed throughout the study areas, separated by at least 400m.

For the **seedling study (part 1; spring 2016)**, we will fully cross two soil depth classes (>>100cm, <100 cm), two soil textures (relatively fine-textured vs. relatively coarse-textured), and three herbivory treatments: simulated browsing, natural browsing, and no browsing. To create a gradient of soil water availability, soil depth and soil texture will be fully crossed (2 depths * 2 textures = 4 depth-texture combinations) and replicated 5 times in Beef Basin and Harts Draw (= 20 plots) and twice on the smaller Alkali Flat and Black Mesa study areas (=8 plots). In total we will have 56 study plots. At each of the plots we will plant 69 sagebrush seedlings, of which 20 will be assigned to each of the three browsing treatments: simulated, natural, and no browsing (total=100 per browsing treatment per soil depth-texture combination). For simulated browsing we will remove 50% of above-ground biomass (clipping from the top of the plants to simulate large ungulate browsing). Both “simulated browsing” and “no browsing seedlings” (total=800) will be protected from deer, elk, cattle, and lagomorphs with seedling protector tubes. The remaining 400 “natural browsing” seedlings will be left unprotected. The remaining 9 seedlings per plot (total = 180) will be distributed across herbivory treatments and retained as ‘sacrifice plants’ for destructive measurements (see below). Clipping will occur in late February/early March to approximate timing of actual mule deer browsing of seedlings,
with access of the site via horseback. Seedlings (from seed collected at the study site) are being raised in a greenhouse in 164cm$^3$ SC10 Cone-tainers ™. Seedlings will be transplanted to the field as early as possible in May (at 4.5 months, ~10cm tall). We will transport water to the field in jugs (2 pints per plant = 17 gallons) and thoroughly water seedlings at planting time and every two weeks for a month; we expect relatively high (at least 60%) transplant success (Dettweiler-Robinson et al. 2013).

For the **seedling study (part 2; spring 2016)**, we will capitalize on planned sagebrush restoration plantings planned by the BLM and UDWR at Alkali, Black Mesa, and Hart’s Point/Draw sites. Once exact project locations are determined, and we are able to determine soil properties at those sites, we will select 300 seedlings (100 per site) that fall across a gradient of soil textures and depths. Half of these seedlings will be left open to a gradient of natural browsing, and the other half will be protected with seedling protector tubes.

For the **adult plant portion of our study**, we will again cross 2 soil depths * 2 texture treatments. These 4 depth-texture combinations will be replicated 5 times in Hart’s Draw/Hart’s Point, 2 times in Black Mesa, and 2 times in Alkali (= 36 plots). Each study plot will be **10 m x 10 m** and fenced. In each plot we will select nine (of ~30) plants in the dominate 15-50 cm height class (324 across all sites) to be evenly divided and assigned to one of three simulated browsing treatments: none, low and high (relative to natural browsing levels in the area). For simulated browsing treatments, we will hand clip leaders following methods outlined in Bilbrough and Richards (1993). Clipping will occur after the first freeze (November) and in spring (Feb/March) to match timing of actual mule deer browsing on adult plants. We will select an additional 3 plants at each site (total = 108)
that are located outside the exclosures and receive natural browsing. We expect these 108 plants to fall along a gradient of natural browsing intensity and that we will be able to relate natural browsing to our clipping treatments.

We will monitor survival and reproduction, as well as height, width, leader length, and percent of live/dead plant area of all target seedlings and adult shrubs throughout the study. Because we may not observe dramatic changes in survival rates in the first few years of our study, we will also closely monitor plant stress. We will use three measures of stress as indicators of potential short- and long-term survival. First, we will measure predawn and midday water potential of all treatment shrubs (n=324) using a Scholander pressure bomb on 3 stems per sagebrush (Scholander et al. 1965). Because our sampling approach will remove a large proportion of biomass of (small) seedlings, we will only assess water potential on the 180 ‘sacrifice seedlings’ (9 seedlings per plot). Second, we will collect leaves from each of adult and seedling plants per herbivory treatment per plot (n=180 seedlings and 324 adults) for carbon isotope analysis using a mass spectrometer through Cornell. Higher $^{13}$C to $^{12}$C ratios indicate increased water stress associated with CO$_2$ access due to changes in plant stomatal conductance (Ferrio et al. 2003). These C isotope ratios measure a plant’s integrated drought response (i.e., over the full growing season as opposed to one-time water potential measurements that can change very rapidly). These C ratios are a key response variable 1) because they provide information on plant drought tolerance (i.e., lower ratios = higher tolerance) (Germino and Reinhardt 2014), and 2) because drought tolerance occurs at the expense of plant growth rate/production (Farquhar et al. 1989). Both water potential and isotope measurements will occur yearly. Third, we will monitor soil moisture dynamics by installing moisture probes
and loggers (EC-5 probe and EM-50 Digital/Analog Data Logger; Decagon Devices) at four depths: 10cm, 30cm, 50cm, and at 125cm or lithic contact, whichever is shallower (though we will auger to lithic contact at all sites). Probes and loggers will be placed in the center of each of the 56 experimental sites (20 Beef Basin, 20 Hart’s Point/Draw, 8 Black Mesa, 8 Alkali) and will generate hourly readings and daily averages throughout the study. We also will install Decagon analog precipitation and temperature gauges in these plots and model seasonal soil moisture movement and available plant soil moisture in the program Hydrus 1D.

To examine feedbacks between plant stress and vulnerability to browsing, we will measure sagebrush defenses (terpenoids) (Kimball et al. 2004) and protein levels (Horwitz and Latimer 2002) once per year (during the clipping periods). We will analyze volatile and protein levels from 5 leaves from each of the adult treatment plants and seedlings per herbivory treatment per plot plus the 108 natural browsing shrubs (n=180 seedlings and 324 adults). All sagebrush growth and stress data will be analyzed as a repeated measures split plot design, treating soil depth*texture combinations as main plots and browsing treatments as sub-plot effects. Site variables (plant and soil cover, shrub densities, etc.), pre-treatment data, and animal use (assessed via track plates, burrow counts, and camera traps) will be screened for inclusion as covariates in the analysis. Preference and intake of browse species are negatively related to terpene concentrations (either total amount, specific fractions, or individual compounds) for wildlife such as mule deer (Schwartz et al. 1980, Personius et al. 1987) and sage-grouse (Remington and Braun 1985), as well as livestock (Ngugi et al. 1995, Riddle et al. 1996). We will use this information to create soil-based spatial data of sagebrush vulnerability (to browse and
drought) across the landscape; vulnerable areas can be targeted (or avoided) for sagebrush restoration efforts.

**Objective 2**

We will combine experimental results with digital soil mapping to classify soils in our study areas according to sagebrush resilience to browsing. To move beyond current soil survey data (which are often coarse and/or inaccurate) we will use digital soil mapping to make spatially explicit predictions of key soil variables (soil depth, water holding capacity) across the study areas. This work has been completed for Beef Basin, and we are proposing new efforts in the Hart’s Point/Hart’s Draw, Black Mesa, and Alkali areas. First, field crews will fully describe soils (according to Schoeneberger et al. 2012) and corresponding vegetation for 40 study locations on Harts Draw, 20 locations in Black Mesa and 20 locations in Alkali Flat study areas. Locations will be chosen using Conditioned Latin Hypercube Sampling (cLHS), a stratified random sampling scheme which selects representative sample locations to capture soil variability (Brungard and Boettinger 2010). We will then use this field data for digital soil mapping (McBratney et al. 2003, Brungard et al. 2015) in a GIS to produce predictions of key soil variables across each study area at ~30m spatial resolution.

**Outputs**

Outputs that will be shared with the UDWR include sagebrush monitoring data, soil field data for all 60 locations, and GIS data layers. Digital soil mapping will produce spatially explicit raster-based predictions of soil depths and water holding capacity throughout our study areas. We will combine this information with experimental data on
sagebrush responses to different soil depths and textures to produce individual GIS layers of drought resistance (measured by C-isotopes) and browse vulnerability (measured via terpenoid levels) throughout the study areas. All of these layers can then be combined to create maps predicting potential for high, moderate, or low restoration success of both seedling and adult sagebrush across the study areas.

STUDY AREA

Our proposed study sites are located in San Juan County, southeastern Utah on BLM portions of the Canyonlands Research Center (CRC). The seedling study (part 1) will be located in the “Beef Basin” area that has experienced sagebrush die-offs over the last three decades (Fig. 3). The seedling study (part 2) and adult plant portion of our study will be located in the “Hart’s Draw/Hart’s Point”, “Black Mesa” and “Alkali” areas where sagebrush stands serve as important mule deer winter habitat (Fig. 3). Beef Basin contains 20 seedling study plots, Harts Draw/Point contains 20 paired seedling and adult sagebrush study plots, and Alkali and Black Mesa each contain eight paired seedling and study plots.
Figure 3. Map of the four primary study areas in Southeastern Utah. Beef Basin and Harts Draw/Point contain 20 study sites each and Alkali and Black Mesa contain eight study sites each.
EXPECTED RESULTS AND BENEFITS

This research will provide information to land managers and scientists who are interested in restoring sagebrush rangelands for wildlife habitat. This research also will inform the broader scientific community by identifying further areas of inquiry for how interactions between biotic factors (browsing) and abiotic factors (soil characteristics) influence plant communities currently and under projected climate scenarios. Broader impacts of the proposed work include direct application to the practice of ecological restoration in Utah. The proposed study areas (Beef Basin, Hart’s Point/Draw, Black Mesa, and Alkali) are important mule deer habitat and have been slated for major sagebrush restoration efforts by the BLM and Utah DWR in the next few years. However, given historic declines in sagebrush in this area, combined with general difficulties in restoring aridlands, there is a strong need to understand why sagebrush thrive and die. By combining our experimental results with digital soils data for the region, we will be able to generate soil-based decision support tools (see “Outputs” above) for identifying and prioritizing areas with the highest resilience to browsing (and hence probability of restoration success) at both seedling and adult plant life stages. Overall, we expect our work to inform restoration activities and help maintain winter habitat for mule deer. We have created a large access database that contains site locations, soil, seedling, and adult sagebrush data collected from 2012-2019 that will be housed at Utah State University.
LITERATURE CITED


