Impact of fuel breaks and soil moisture on annual grass invasion

2022-23 ESS SUPER Program

Skills for Undergraduate Participation in Ecological Research

Madeline Gillet

Dr. Morgan Roche

Instructor: Dr. Stacy Lynn

TA: Sean Geer

May 7, 2023

Names & Affiliations

Madeline Gillet[1], Rylee Sharkey[2], Morgan D. Roche[3]

1. Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO 80523
2. Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO 80523
3. Natural Resources Ecology Laboratory, Colorado State University, in cooperation with U.S. Geological Survey, Fort Collins Science Center, Fort Collins, CO 80523

Abstract

As wildfires become more frequent and severe in sagebrush ecosystems, many landscapes are becoming trapped in cycles of wildfire followed by invasion of nonnative annual grasses, and many native plant species never recover. Fuel breaks are a promising management tool to control the spread of fire and the subsequent loss of native sagebrush vegetation, but more research is needed to assess the efficacy of different types of fuel breaks in various geographic areas and climate conditions. It is also important to understand how installing fuel breaks will affect the risk of invasion, as they are another disturbance to the landscape. In this study, we aimed to understand the impact three types of fuel breaks have on vegetation composition in areas of varying annual soil moisture. We compiled recent data about 305 fuel breaks installed in 2010 and created a generalized linear model comparing variables before (2007-2009) and after (2018-2020) installation. We found a statistically significant relationship between soil moisture and annual grass invasion: fuel breaks at lower soil moistures had more invasion. We also found a statistically significant relationship between fire occurrence near fuel breaks and annual grass invasion: there was more invasion near fuel breaks touched by fire. With more information about fuel breaks, managers will be better able to minimize the spread of fires and annual grass invasion and conserve vulnerable sagebrush ecosystems.

Introduction

Wildfires in the sagebrush biome

Disturbances can have an enormous impact on any type of ecosystem by fundamentally shifting certain dynamics and characteristics. The effects of repeated disturbance can be devastating for ecosystems that are particularly fragile or not adapted to increasing disturbance due to climate change, such as those in the sagebrush biome. Sagebrush ecosystems in the western United States are rangeland ecosystems that have always experienced periodic wildfires, but the increasing severity of their fire regimes has been causing stress on native vegetation and animals living there. The human-grass-fire cycle has been documented in this biome and shown to be devastating for native vegetation (Fusco et al., 2021). Fires start, most often due to human activity (Fusco et al., 2021), and spread throughout the landscape. The speed at which the fires spread and the severity of the fires can be exacerbated by drier conditions. After the fire, it takes many native species a long time to regenerate and recover (Nelle et al., 2000), so invasive annual grasses such as Bromus tectorum, or cheatgrass (Williamson et al., 2019), have an opportunity to take over.

Figure 1. A sagebrush ecosystem has a brown strip fuel break running through it. (Forest and Rangeland Ecosystem Science Center, 2018)

In an environment disturbed by fire, these annual grasses are successful because they can outcompete native vegetation in many ways. They can live in a wider range of temperatures, soil moisture, soil nutrient gradients, and other conditions (Mahood et al., 2019).

Fuel breaks and fire prevention

To curb this problem, it is usually more effective for environmental managers to prevent fires from occurring in the first place than to try to restore areas that have already been taken over by invasive annual grasses (Davies et al., 2011). Fuel breaks are a method of fire prevention that has been proposed in some of the most susceptible areas in the sagebrush biome. A fuel break is a broad term describing either a natural or constructed structure that changes fuel characteristics and thus changes the behavior of fire so that it is less intense, easier to control, or prevented from spreading. There are several different types of fuel breaks, but study discusses three: mowed, green strips and brown strips. Mowed fuel breaks are created by mowing vegetation down to a shorter height and pushing vegetation aside. Brown strips are formed by removing vegetation so that there is exposed bare soil. Green strips are fuel breaks made of typically non-native vegetation that can outcompete invasive annual grasses present in the landscape. (Shinneman et al., 2019) Fuel breaks show promise, but there is still a lot scientists don't know about them, including how effective they are, where they are most effective, the impacts they have on organisms, and if they themselves may increase the risk of invasion.

Goals of the study

This study aims to fill part of the wide gap in research about the effectiveness of different types of fuel breaks in the sagebrush biome and their relationship with soil moisture. I suggest that in landscapes with fuel breaks installed, there will be more annual grass cover in areas with lower annual soil moisture 10 years after fuel break installation. Based on the existing body of literature, it seems that lower soil moisture makes a suitable habitat for cheatgrass to outcompete native vegetation, as well as making fire disturbance more likely in the first place.

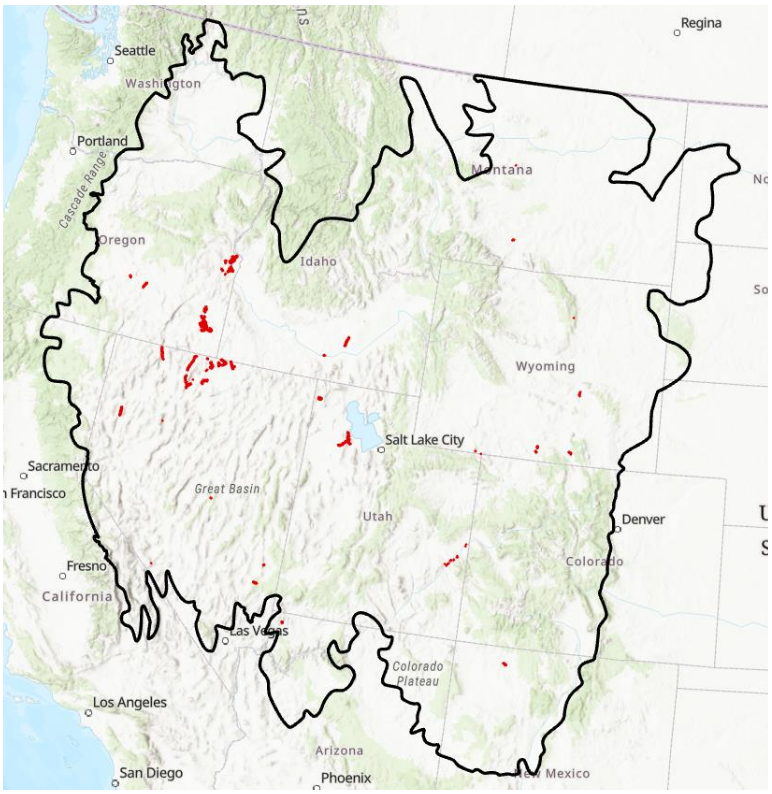

Figure 2. The sagebrush biome (outlined in black) covers a significant portion of the western United States, spanning several states. This study focuses on a sample of 305 fuel breaks installed in 2010 (red). (created by M. Gillet)

Research Questions and Hypotheses

Research Question:

How is annual grass cover impacted around fuel breaks of different types in the sagebrush biome by (a) annual soil moisture and (b) being burned by wildfire?

Research Hypotheses:

- In sagebrush landscapes with fuel breaks installed in 2010, there will be more annual grass cover in areas with lower annual soil moisture 10 years after fuel break installation than before installation.

- In sagebrush landscapes with fuel breaks installed in 2010, there will be more annual grass cover near fuel breaks that were touched by wildfire 10 years after fuel break installation than before installation.

Emergent Null Hypotheses:

- In sagebrush landscapes, there is no difference in annual grass cover between areas with low annual soil moisture and high annual soil moisture before fuel break installation and 10 years after installation.

- In sagebrush landscapes, there is no difference in annual grass cover between areas touched by a wildfire and those not touched by a wildfire before fuel break installation and 10 years after installation.

Explanation:

In areas with both low soil moisture and where the BLM thought fuel breaks would be needed are likely to be areas susceptible to wildfire and subsequent annual grass invasion after the disturbance. Low soil moisture indicates drier conditions which makes wildfire more likely. There may not be much more annual grass invasion in areas with lower soil moisture than areas with higher soil moisture due to effective fuel breaks, but there is likely some difference.

In areas near fuel breaks that were touched by wildfire, annual invasive grass would have a better chance of taking over because they need fewer resources than native vegetation and they take less time to grow. Once perennial grasses are burned, annual grasses can establish quickly.

Methods

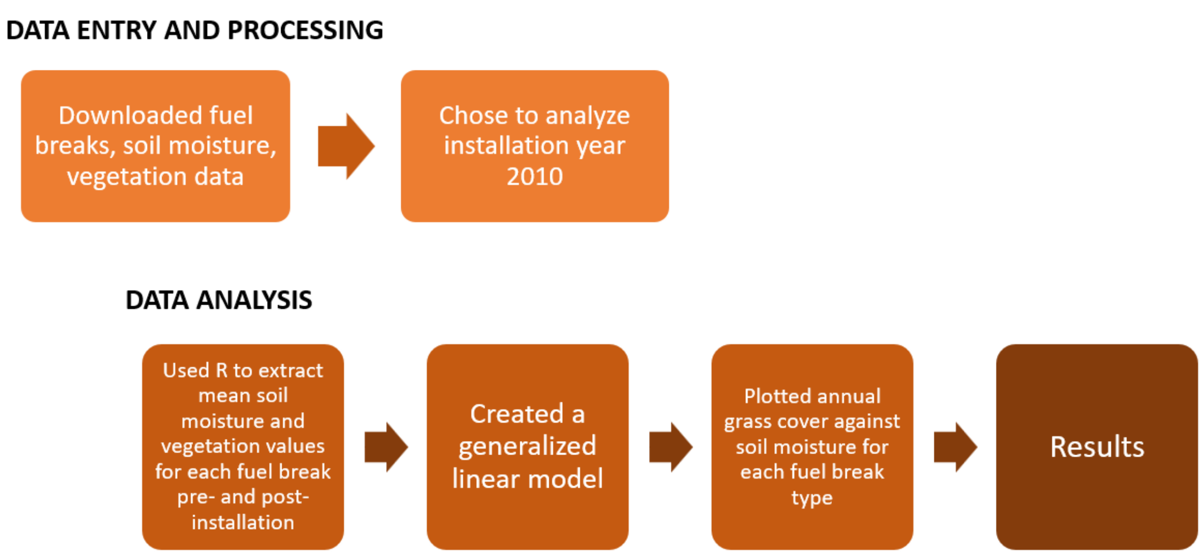

Figure 3. I conducted my methods by downloading and processing data, then data analysis.

Data Entry and Processing

As outlined in Figure 3, I first gathered data already collected and published by other organizations or researchers. The annual soil moisture raster data, the annual vegetation raster data, and the wildland fire data came from USGS which I downloaded online. The soil moisture data contains values that represent the climate average over the years 1985-2010. The vegetation rasters (years 2007-2010 and 2018-2020) contain values that represent the percent of vegetation cover that is annual grasses, mainly cheatgrass but also other invasive annual grasses. The fuel breaks data came from the researchers Weise et al., and it is still in review. The fuel breaks data includes fuel breaks installed by the Bureau of Land Management in the sagebrush biome with attributes such as fuel break type, maintenance years, and installation years. These data are updated to the year 2021. After reviewing the fuel breaks and soil moisture datasets, I chose to analyze the installation year 2010 because it had 305 fuel breaks of different types across an expansive geographic extent and a variety of soil moisture values.

Data Analysis

To analyze these data spatially, I utilized ArcGIS Pro to make maps and do statistical analysis. I first created a 150 meter buffer around the fuel breaks to account for vegetation that may be impacted by the installation of the fuel break itself, as opposed to a factor like soil moisture. To get a picture of the vegetation around within the buffer of the fuel breaks before and after installation, I extracted mean vegetation values for the years 2007-2009 and again for 2018-2020 using R. The layer with the 2007-2009 average represented "pre-installation vegetation" and the layer with the 2018-2020 average represented "post-installation vegetation". It was important to get average values from a few years to have more accurate representations of vegetation around these fuel breaks.

I extracted the pre-installation vegetation and post-installation vegetation values to the area of the buffered fuel breaks. I then repeated the process with the soil moisture data. Then, every fuel break had an average value for annual soil moisture, and pre- and post-installation annual grass cover which could be used for statistical analysis.

I repeated the above process with a 500 meter area surrounding the fuel breaks that would serve as a control to compare results to.

To understand the effects of fuel break type and soil moisture on annual grass cover, I created a generalized linear model. In R, I plotted the change in annual grass cover against soil moisture, and highlighted the data points based on which fuel break type they were – mowed, brown strip, or green strip - there were fuel breaks within the dataset labeled "other" that were removed due to a lack of information. There were two of these graphs, one for pre-installation and one for post-installation, so I could compare the two. I am also comparing these fuel break values to areas without fuel breaks that are my control. We ran statistical tests with our model to test for significance, as well.

I repeated the above process by creating a generalized linear model with the same predictor and response variables, but according to the occurrence of a fire or not. 41 fuel breaks were touched by a fire. Again, I ran statistical tests to get results about the significance of the relationship between variables.

Data Interpretation

In the graphs, I looked for patterns that indicate a relationship between each variable being plotted and/or analyzed (grass cover, soil moisture, fuel break type, fire occurrence). I looked for statistical significance in the tests I ran that indicate a relationship between variables. I also looked for differences between the 500 meter control buffer and the 150 meter buffer containing the fuel breaks.

Results

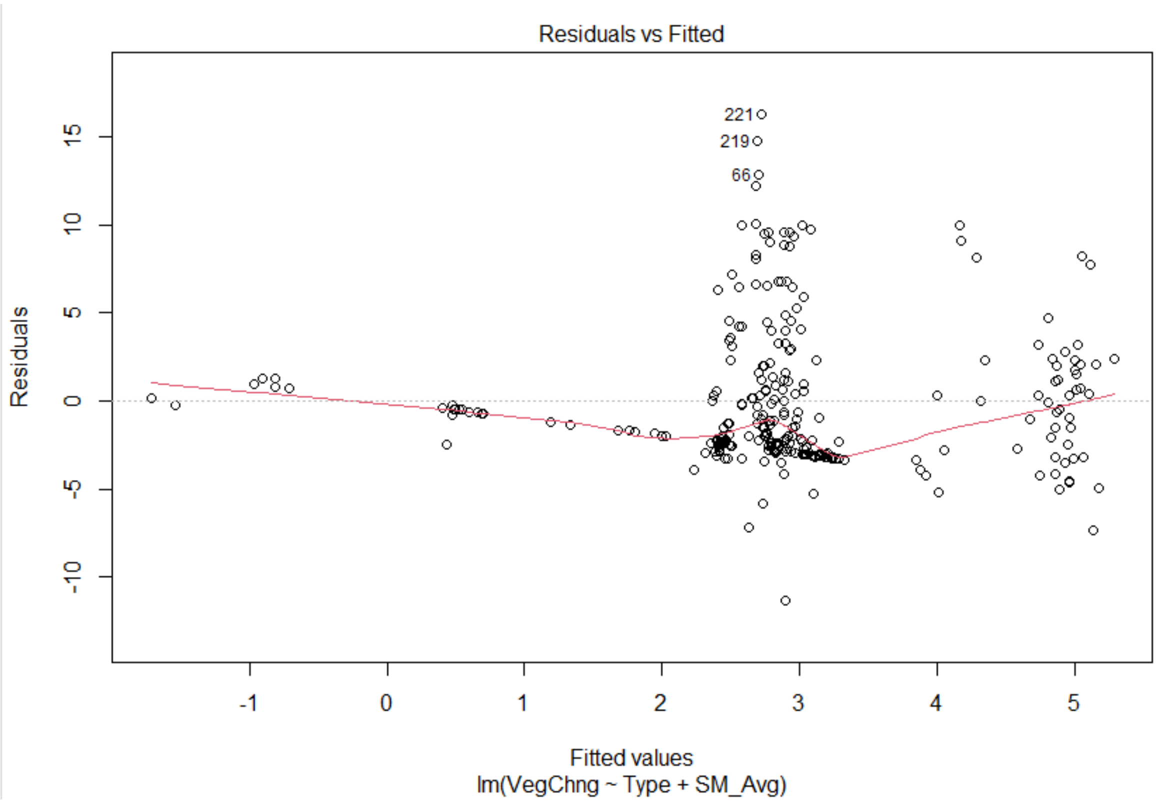

Figure 5. A graph of fitted values (x-axis) and residuals (y-axis) for the linear model written simply as: Grass cover change = (Soil Moisture)x + Fuel Break Type.

I created and plotted a generalized linear model for average annual soil moisture and change in annual grass cover over 10 years as seen in Figure 5. The model had an AIC value of 1651.446, indicating a good fit.

The linear model yielded a p-value of 2.811e-05. According to ANOVA tests, there is a statistically significant relationship between annual soil moisture and annual grass cover, and the results would likely be repeated with a new sample. Figures 6 and 7 more clearly show the linear model represented by each fuel break type for both fuel break areas and control areas.

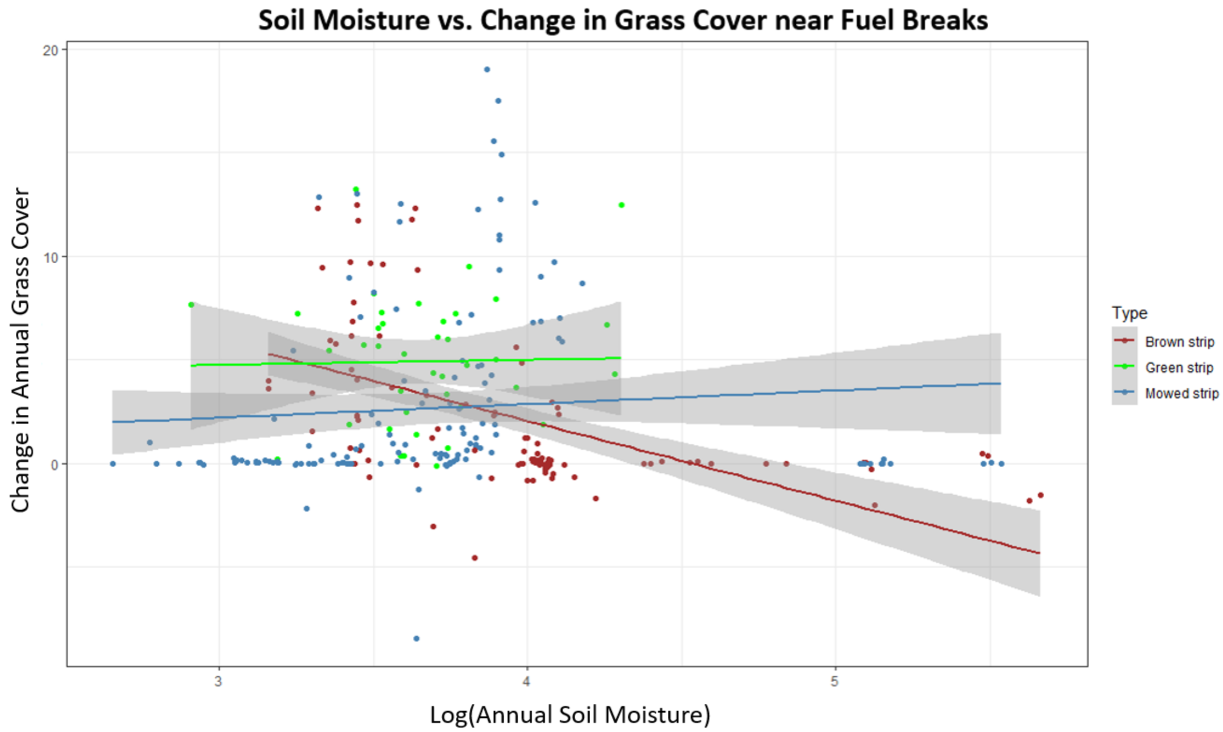

Figure 6. The linear model graph shows annual soil moisture (x-axis) and change in grass cover over 10 years (y-axis) near fuel breaks.

According to Figure 6, every strip type had an average increase in annual grass cover 10 years after fuel break installation. Green strips had the highest overall, with a slight increase across the soil moisture gradient. Mowed strips had a greater increase in annual grass cover over the soil moisture gradient. Brown strips had higher annual grass cover at lower soil moistures which decreased as soil moisture increased. Clearly, there are many more fuel breaks with a great increase in grass cover at lower soil moistures.

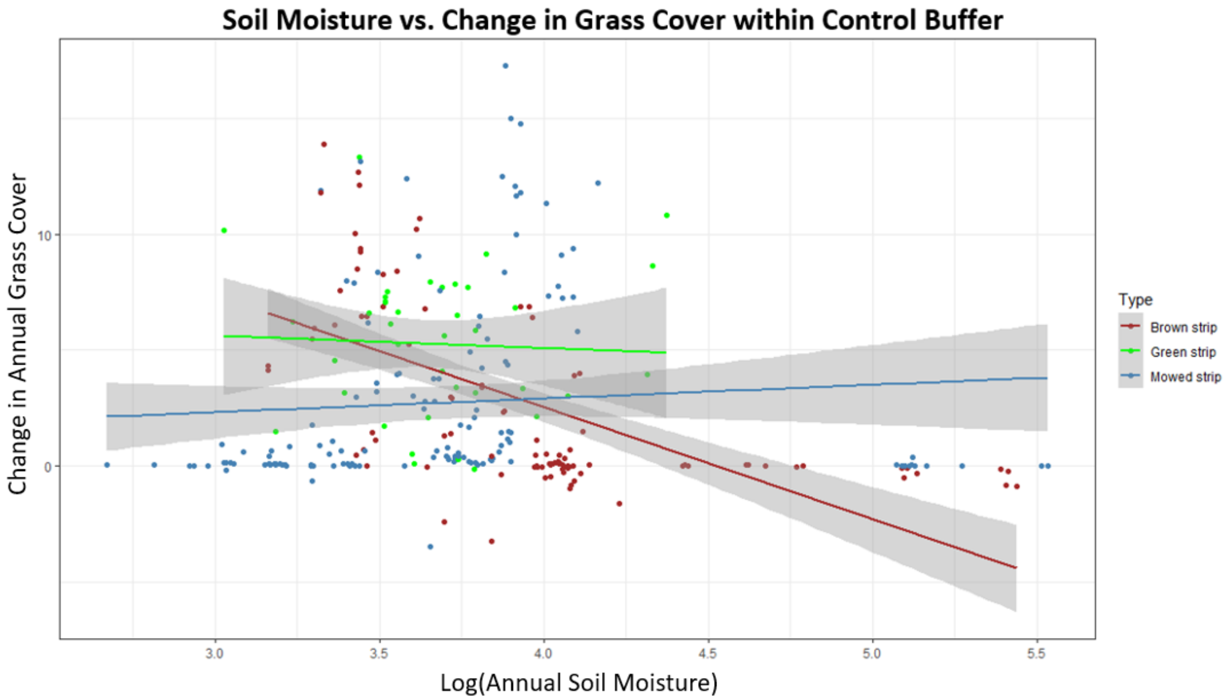

Figure 7. The linear model graph shows annual soil moisture (x-axis) and change in grass cover over 10 years (y-axis) in areas without fuel breaks.

According to Figure 7, there is not much difference between annual grass cover in the control area and annual grass cover near fuel breaks, although green strips have a slight decrease in cover as soil moisture increases.

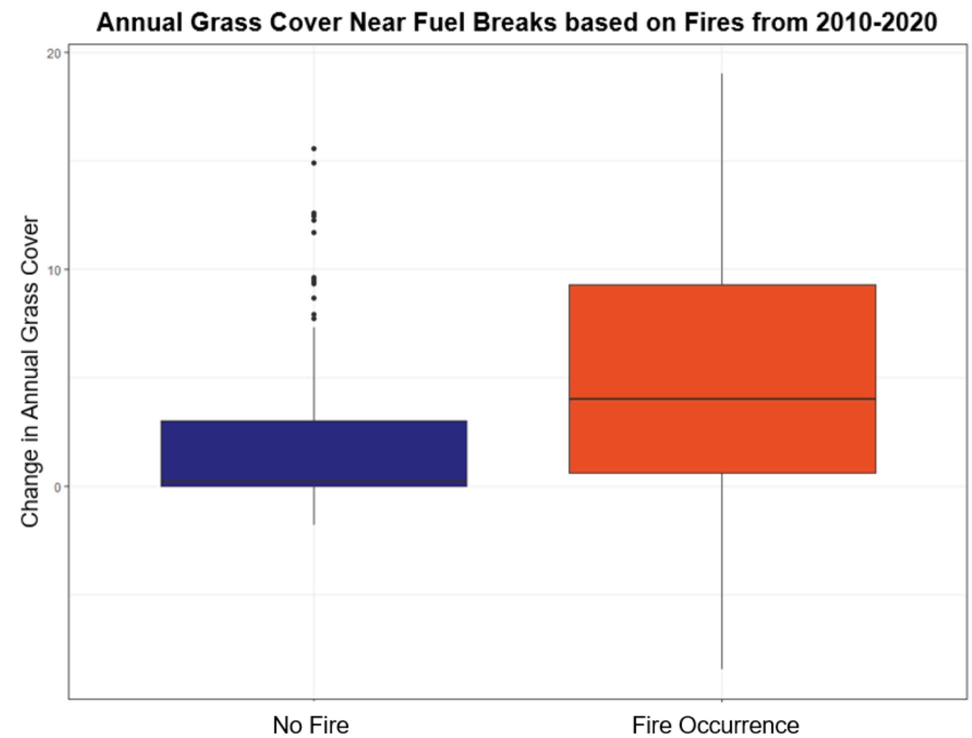

Figure 8. This box plot shows change in annual grass cover 10 years after fuel break installation near fuel breaks that have been touched by a fire and fuel breaks not touched by a fire between 2010-2020, according to the linear model: Grass cover change = (Soil Moisture)x + Fire Occurrence.

As seen in Figure 8, the linear model, Grass cover change = (Soil Moisture)x + Fire Occurrence, is represented graphically based on whether there was a fire between 2010 and 2020. The linear model yielded a p-value of 4.761e-09. There was an AIC value of 1634.313. According to ANOVA tests, there is a statistically significant relationship between annual soil moisture and annual grass cover, and the results would likely be repeated with a new sample.

Discussion

Soil Moisture and Invasion

According to the graphs and results yielded from data analysis, there is a significant relationship between soil moisture and grass cover change. On average, every strip type had increases in invasion 10 years after the fuel breaks were installed in 2010. Lower soil moisture is correlated with greater increases in annual grass cover, both near fuel breaks and in the control areas. However, this is more prominently observed in areas with a soil moisture below a value of 75. Above it, there is not much grass cover change occurring in the few mowed strips and brown strips installed there. This is in line with my hypothesis because invasive annual grasses in the sagebrush biome are more likely to take over when there are fewer resources like water and native vegetation is, therefore, more vulnerable. Annual grasses can establish very quickly in areas where perennial grasses and other native vegetation have been disturbed, whether by fire or by climate conditions.

Fuel Break Type

There are some varying trends in annual grass cover change according to fuel break type. According to figure 6, brown strips had the highest level of invasion at lower soil moistures, so they are more suitable for areas with higher soil moisture. The fuel breaks with higher soil moisture even had a slight decrease in annual grass cover in some cases, enforcing the idea that native vegetation is more resilient in those climate conditions. Mowed strips had the least invasion at lower soil moistures, so they would be the best fuel break for these areas. Green strips had the greatest average increase in annual grass cover, though there were fewer fuel breaks present at a greater soil moisture in this sample. Green strips should not be installed at lower soil moistures, and not until more is known about their invasion risk at higher soil moistures.

The limited variation between the fuel breaks and the control area (Figure 7) indicates that the installation of the fuel breaks is not in itself a significant disturbance in relation to invasion.

Fire Occurrence

There was also statistical significance in the model containing fire occurrence. On average, fuel breaks both touched by fire and not touched by fire had an increase in annual grass cover 10 years after installation. However, Figure 8 shows a greater average increase of annual grass cover from 2010-2020 in areas touched by fire than those not touched by fire. This is in line with what the literature states because fires are a significant disturbance that destroys perennial grasses and other native vegetation, allowing invasive grasses to quickly take over. Invasion is also more likely in areas that are drier and more susceptible to fires already, so understanding the relationships among these variables better is essential in future studies. It seems that in areas with greater fire occurrence, fuel break installation will be beneficial as these areas are more at risk.

Limitations of the Study and Recommendations

This sample had far fewer fuel breaks with a fire than without a fire, so more research with a greater sample could be helpful in validating results. There were also varying numbers of each fuel break type, so again, more research done with a greater sample of each is warranted. Green strips, in particular, must be studied at higher soil moistures to understand how they affect annual grass invasion. Furthermore, there were only a handful of mowed strips and brown strips in this sample at higher soil moistures, so further study is needed.

Repeating studies with greater samples over time will yield more accurate information to help managers decide where, when, and what to install in these ecosystems. For now, managers should focus on areas with the highest risk – areas with more frequent fires and lower soil moisture.

Conclusions

In rapidly degrading ecosystems like those of the sagebrush biome in the United States, effective and timely management decisions are critical. The research indicates that fuel break installation must be made more cautiously in the future according to the soil moisture of the area, as it is a significant variable in relation to annual grass invasion. The amount of literature about the impacts of fuel breaks on annual grass cover according to climate variables like soil moisture is still small, and more study is needed to understand the relationship between these variables. There are many impacts on the ecosystem, and the benefit of the fuel break must be outweighed by the disturbance of the fuel break. This ecosystem is quickly fading, and it is important to balance action with caution while we wait for more research.

References

Davies, K. W., Boyd, C. S., Beck, J. L., Bates, J. D., Svejcar, T. J., & Gregg, M. A. (2011). Saving the Sagebrush Sea: An ecosystem conservation plan for big sagebrush plant communities. *Biological Conservation*, *144*(11), 2573–2584. https://doi.org/10.1016/j.biocon.2011.07.016

Fusco, E. J., Balch, J. K., Mahood, A. L., Nagy, R. C., Syphard, A. D., & Bradley, B. A. (2021). The human–grass–fire cycle: how people and invasives co-occur to drive fire regimes. *Frontiers in Ecology and the Environment*, *20*(2), 117–126. https://doi.org/10.1002/fee.2432

Mahood, A. L., & Balch, J. K. (2019). Repeated fires reduce plant diversity in low-elevation wyoming big sagebrush ecosystems (1984–2014). *Ecosphere*, *10*(2). https://doi.org/10.1002/ecs2.2591

Nelle, P. J., Reese, K. P., & Connelly, J. W. (2000). Long-Term Effects of Fire on Sage Grouse Habitat. *Journal of Range Management*, *53*(6), 586. https://doi.org/10.2307/4003151

Roche, MD; DJ Saher; EK Buchholtz; MR Crist; DJ Shinneman; CL Aldridge; BE Brussee; PS Coates; CL Weise; JA Heinrichs. Ecological trade-offs associated with fuel breaks in the sagebrush ecosystem. *In review.*

Shinneman, D. J., Germino, M. J., Pilliod, D. S., Aldridge, C. L., Vaillant, N. M., & Coates, P. S. (2019). The ecological uncertainty of wildfire fuel breaks: Examples from the Sagebrush Steppe. *Frontiers in Ecology and the Environment*, *17*(5), 279–288. https://doi.org/10.1002/fee.2045

Weise, CL; PS Coates; MA Ricca; MR Crist; DJ Shinneman; CL Aldridge; JA Heinrichs. Comprehensive fuel breaks data for the western U.S. *in review*

Williamson, M. A., Fleishman, E., Mac Nally, R. C., Chambers, J. C., Bradley, B. A., Dobkin, D. S., Board, D. I., Fogarty, F. A., Horning, N., Leu, M., & Wohlfeil Zillig, M. (2019). Fire, livestock grazing, topography, and precipitation affect occurrence and prevalence of cheatgrass (Bromus tectorum) in the Central Great Basin, USA. *Biological Invasions*, *22*(2), 663–680. https://doi.org/10.1007/s10530-019-02120-8

Acknowledgements

I would like to acknowledge and thank the authors of the original fuel breaks dataset, Weise et al., which is in review, as well as the authors of the updated dataset that I used, Roche et al., which is also in review. This project was completed as part of the Ecosystem Science and Sustainability SUPER Program (Skills for Undergraduate Participation in Ecological Research).

Appendix 1

1. **Data Collection**
   Data collection was not a part of this project.

2. **Data Entry and Processing**
   A. Raster data in GIS
      i. *Fuel breaks data*
         a. The original dataset source:
         Weise, CL; PS Coates; MA Ricca; MR Crist; DJ Shinneman; CL Aldridge; JA Heinrichs. Comprehensive fuel breaks data for the western U.S. *in review*
         b. The team that built off of that original dataset:
         Roche, MD; DJ Saher; EK Buchholtz; MR Crist; DJ Shinneman; CL Aldridge; BE Brussee; PS Coates; CL Weise; JA Heinrichs. Ecological trade-offs associated with fuel breaks in the sagebrush ecosystem. *In review.*

      ii. *Vegetation cover/type data*
         Rigge, M.B., Bunde, B., Shi, H., Postma, K., 2021, Rangeland Condition Monitoring Assessment and Projection (RCMAP) Fractional Component Time-Series Across the Western U.S. 1985-2020 (ver. 2.0, October 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P95IQ4BT.

      iii. *Annual soil moisture data*
         O'Donnell, M.S. and Manier, D.J., 2022, Soil-climate estimates in the western United States: climate averages (1981-2010): U.S. Geological Survey data release, https://doi.org/10.5066/P9ULGC03.

3. **Data Analysis**
   A. Raster data in GIS
      - I began by analyzing the fuel breaks data to select a suitable installation year to focus on. 2010 has numerous fuel breaks across several states in the sagebrush biome, so we selected it.
      - I gathered vegetation cover data for 2008, 2009, 2010, and 2020 for each geographical area with fuel breaks being included.
      - I used the data from the shapefiles in ArcGIS Pro to plot percent cover of annual grass against the year for each geographical area in the analysis.
      - I plotted percent cover of annual grass against soil moisture for each area in the analysis.
      - I did some statistical tests that are yet to be decided by my mentor and I to understand if there are statistically significant differences between these variables.

4. **Data Interpretation**

A. Raster data in GIS
    - I am looking for patterns in my graphs that indicate a relationship between each variable being plotted (vegetation, soil moisture, year).
    - I am looking for statistical significance in the tests I run that indicate a relationship between variables.
    - I am looking for differences between control areas without fuel breaks and areas with fuel breaks that have similar annual soil moisture.