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Colorado – Fort Collins**



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**Santa Ana Pueblo Agriculture**  
Supporting Rangeland Monitoring and Decision Making in New Mexico with NASA  
Earth Observations

**DEVELOP Technical Report**

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Sasha Gannon, Analytical Mechanics Associates  
Jacquelyn Cordova, Analytical Mechanics Associates  
Jason Dutcher, Analytical Mechanics Associates  
Salome Oumarou Wate, Analytical Mechanics Associates

***Advisors:***

Dr. Tony Vorster, Colorado State University, Natural Resource Ecology Laboratory (Science Advisor)  
Nicholas Young, Colorado State University, Natural Resource Ecology Laboratory (Science Advisor)  
Christopher Tsz Hin Choi, Colorado State University, Natural Resource Ecology Laboratory (Science Advisor)  
Dr. Paul Evangelista, Colorado State University, Natural Resource Ecology Laboratory (Science Advisor)  
Dr. Catherine Jarnevich, Colorado State University, Natural Resource Ecology Laboratory (Science Advisor)

***Lead:***

Truman Aranella (Colorado – Fort Collins)

## 1. Abstract

The Pueblo of Santa Ana Department of Natural Resources (DNR) manages over 140,000 acres of rangeland in New Mexico, utilizing both Traditional Ecological Knowledge and geospatial technologies to address challenges like overgrazing, drought, and biodiversity conservation. Our team partnered with the DNR to conduct a feasibility study using the Rangeland Analysis Platform (RAP), which incorporates Earth observations from Landsat missions. Specifically, Landsat 5 Thematic Mapper, Landsat 7 Enhanced Thematic Mapper Plus, Landsat 8 Operational Land Imager, and Landsat 9 Operational Land Imager-2 to support adaptive management. We used RAP to assess trends in bare ground cover and biomass across the pueblo's rangelands from 1985 to 2023, evaluating its accuracy by comparing RAP data to on-the-ground field measurements. Results indicated that RAP effectively estimates bare ground cover but showed limitations in estimating production in the arid environment of Santa Ana Pueblo. Overall, bare ground cover showed stable or decreasing trends over the study period, suggesting that the DNR's land management practices have bolstered resilience against drought impacts over time. Further pixel-level analysis highlighted specific areas of interest, such as juniper reduction zones and riparian areas, where ground cover either stabilized or improved. While RAP offers a valuable tool for long-term bare ground cover monitoring, our findings underscored the need for an alternative data source for effective long-term biomass monitoring in Santa Ana Pueblo. These findings provide Santa Ana Pueblo with data to guide sustainable rangeland practices, enhancing ecological resilience and informing adaptive strategies to manage climate variability across diverse rangeland conditions.

**Key Terms:** rangeland monitoring, NASA Earth Observations, Santa Ana Pueblo, remote sensing, grazing management, Rangeland Analysis Platform

## 2. Introduction

### *2.1 Background Information*

Indigenous peoples have utilized unique sciences and Traditional Ecological Knowledge (TEK) to develop and sustain regenerative land management practices for generations (Bayer & Montoya, 2009). As a result of European colonizing efforts, many Indigenous peoples' traditional systems, and the lives of those who rely on and benefit from them, have been significantly impacted (American Horse et al., 2023). To continue fulfilling their responsibilities of ensuring the balance and sustainable stewardship of the Earth and its ecosystems, many Indigenous communities have chosen to incorporate Western GIS technologies into their long-term land management plans (Pearce & Louis, 2008; Cutright-Smith, 2013).

Santa Ana Pueblo, a sovereign Native nation located in north central New Mexico, utilizes geospatial technologies, field-based monitoring techniques, and TEK to help steward over 140,000 acres of rangeland (Campos-Marquetti, Harper, & Ginter, 2014). Much like other areas in the state, Santa Ana Pueblos' rangelands are dominated by blue grama and western wheatgrass and are vulnerable to overgrazing and drought (United States Department of Agriculture, 2024). Overgrazing can threaten not only specific grass species and the lifeforms that depend on them, but also the Pueblos' generational land use practices. Consequences of overgrazing such as biodiversity loss, land degradation, and influx of invasive plant species, pose many threats to Pueblo life. The Santa Ana Pueblo strives to maintain healthy and productive rangelands through the effective management of rangeland grazing systems, maintenance of native rangeland plant communities, and efforts to increase pasture resiliency to drought.

The Range and Wildlife Division of the Department of Natural Resources (DNR) at Santa Ana Pueblo, is tasked with ensuring the health and productivity of the Pueblos' rangelands. The DNR focuses on developing and implementing programs that protect, preserve, and enhance the Pueblos' natural resources for current and future tribal members. They do this by assessing the condition and health of Pueblo lands (including air, water, and land quality), identifying existing and potential issues within the landscape, and then working with tribal leadership to develop and implement those plans to address their challenges.

Over the past decades, the Range and Wildlife Division has expanded their rangeland and grazing management programs by: increasing monitoring efforts that includes tracking precipitation and drought conditions through rain gauges and weather stations, monitoring grazing plots through photo-point monitoring and line point intercept-transect data, collecting long-term livestock forage data, creating GPS collaring projects to track the distribution, density, and feeding patterns of wildlife in various rangeland areas and developing rangeland grazing production models using clip-plot data and GIS modeling. In addition to the current work being done with GIS at the DNR, the DNR would like to utilize more available remote sensing data (1985 – 2024) to monitor long term vegetation trends and land management strategies. Studies show that utilizing GIS and remote sensing technologies can help monitor vegetation, estimate productivity, map bare ground coverage, evaluate grazing impact and the effects of drought, and overall aid in assessing rangeland health (Roberts et al., 2022; Jones et al., 2020). Using remote sensing technologies like NASA’s Landsat satellites enables researchers and rangeland managers to conduct a wide variety of studies that lead to informed changes to address climate, conservation, biodiversity, and agricultural needs (Jones et al., 2018; Liu et al., 2022; Rikimaru et al., 2002).

Although data provided by these emerging remote sensing technologies is indeed helpful, researchers express that they are not meant to take the place of ground monitoring and management but are rather tools that assist in the adaptive management of rangelands (Stephenson, 2019). Therefore, utilizing remote sensing technologies in tandem with field data can offer a broader understanding of rangeland conditions over time. This contributes to the effective evaluation of previous land management practices and inform future sustainable rangeland management strategies. To support the DNR in further monitoring their rangeland and grazing management efforts, this project focused on utilizing both on-the-ground clip plot data collected by Santa Ana Pueblo and NASA Earth observations’ data through the Rangeland Analysis Platform (RAP). RAP is an online tool that combines NASA satellite data with over 75,000 on-the-ground vegetation measurements to analyze and map vegetation across the United States, including data on perennial and annual herbaceous and shrub, tree, and bare ground percent cover. According to the website, RAP then utilizes cloud computing and machine learning technology to analyze trends in the data, making it an effective tool for developing new rangeland management strategies as well as evaluating current and past rangeland management practices (Rangeland Analysis Platform, n.d.).

## ***2.2 Project Objectives***

For this project, we established three objectives to address the concerns and needs of our partner. The first objective tested the relationship between Santa Ana Pueblo field data and RAP data (1985–2023) to determine accuracy and reliability of the RAP tool. Research shows that the accuracy of remote sensing technologies in arid environments, like that of Santa Ana Pueblo, can be challenging due to sparse vegetation, low biomass levels, and high soil background reflectance (Almalki et al., 2022). Therefore, conducting a feasibility analysis comparing RAP biomass, herbaceous, and bare ground cover to Santa Ana Pueblo field data is critical in determining if and how RAP can be utilized in future DNR rangeland monitoring efforts.

Our second objective is to use RAP data to identify and analyze trends in vegetation and bare ground over time by rangeland unit. This helped to evaluate individual pasture characteristics over time. Our third objective was to focus on identifying and analyzing trends in bare ground percent cover over time at a finer scale using RAP. All these objectives aid in understanding rangeland conditions across different management approaches and vegetation types to inform adaptive management. This project aimed to enhance the Santa Ana Pueblos’ rangeland monitoring and grazing management, particularly during droughts, by providing reliable remote sensing data that can be utilized cross-scale. The goals of these objectives also include an evaluation of rangeland productivity and cover conditions in the Santa Ana Pueblo from 1985 to 2023. This provides insights into historical and current trends. The analysis informs adaptive management strategies by highlighting areas of improvement and decline across various management approaches and vegetation types.

## ***2.3 Study Area***

The study area for this project was Santa Ana Pueblo, located in north central New Mexico, including the rangeland units managed by the DNR. These units represent various management types including those used for grazing livestock (Grazing Areas), those used to mitigate overgrazing during times of drought (Drought Relief), and those set aside for natural wildlife use (Wildlife; Figure 1). Additionally, since 2015 Santa Ana Pueblo rangelands also include Kwii Kee Nee Poo, a unit of land west of the Pueblo, and a smaller northwestern unit set aside for tribal ceremonial use. Each of these rangelands are characterized by a mix of arid grasslands, shrublands, and riparian areas. The pastures, spread across the Pueblo's lands, serve as critical grazing areas for livestock and are key to the community's rangeland management and cultural conservation efforts (DeLonge & Basche, 2018; Eekhout et al., 2018). Although Kwii Kee Nee Poo and the northwestern ceremonial area do not include field clip plot data and therefore cannot be included in our comparison of the accuracy between RAP and field data, they are included in this study as per our partners request and are part of our analysis for bare ground cover in both RAP and rangeland units. Including both Kwii Kee Nee Poo and the northwestern ceremonial area in our finer bare ground cover analysis allows us to provide baseline RAP data on those areas to Santa Ana Pueblo for use in future land management plans.

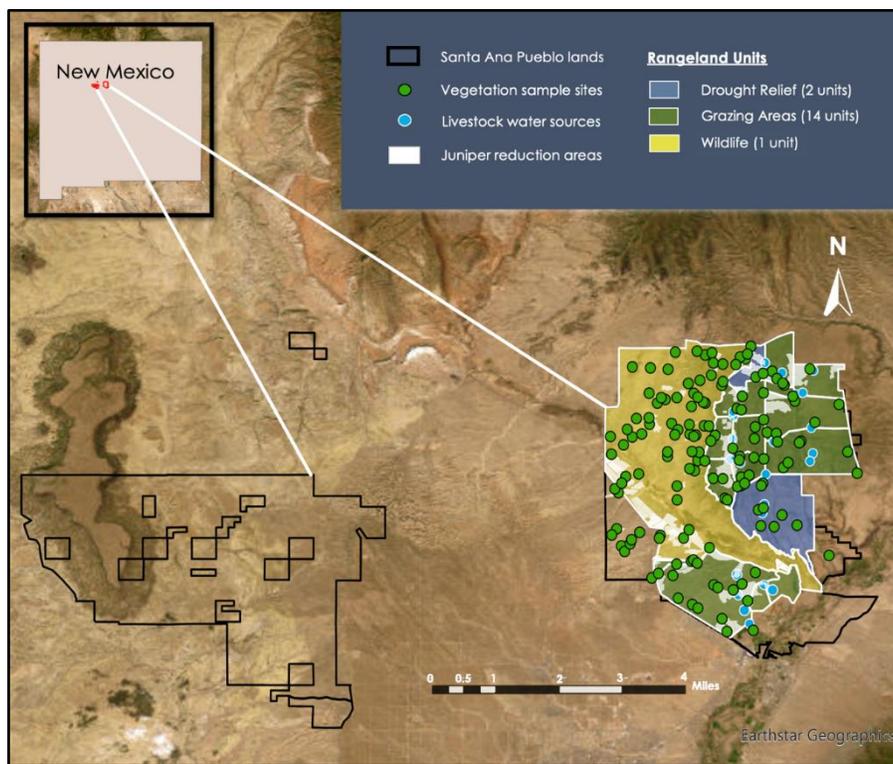


Figure 1. Map of study area including rangeland pasture units and various field data from Santa Ana Pueblo.

### 3. Methodology

#### 3.1 Data Acquisition

To acquire RAP datasets for this study, we downloaded yearly biomass and bare ground rasters for our study period from the RAP website. RAP provides data at a 30-meter resolution using satellite imagery from multiple Landsat missions, including Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Landsat 8 Operational Land Imager (OLI), and Landsat 9 OLI-2 (RAP 3.0, 2022). The DNR provided previously acquired field data sets for plot-specific biomass and bare ground field measurements. This gave us the foundational data needed to test the relationship between Santa Ana Pueblo field data and RAP data. Supplementary datasets provided by the Pueblo included rain gauge data, pasture boundary shapefiles, and juniper reduction areas. These datasets offered critical context for understanding land management practices and ecological conditions within the rangeland units.

### ***3.2 Data Processing***

To prepare the RAP data for analysis, we first loaded the rasters into ArcGIS Pro (version 3.3.0), clipping them to fit our study area using the Clip Raster tool. To process the clip plot field data provided by Santa Ana Pueblo, we created a 26 m radius buffer area around each clip plot point (reflecting the Pueblo's vegetation sample site protocols) to ensure accurate representation of each data point. Next, we ran the Zonal Statistics tool on each raster to create statistics within the 26 m radius buffer area of each clip plot. We then exported the zonal statistic results and compiled them into CSV files matching their corresponding field data points. We then used R (version 2024.09.0 Build 375) for temporal data organization to combine individual rasters into a multidimensional raster, facilitating a structured view of bare-ground coverage over time.

### ***3.3 Data Analysis***

#### ***3.3.1 Evaluation of the Rangeland Analysis Platform (RAP) at Santa Ana Pueblo***

To compare the relationship between Santa Ana Pueblo field data and RAP data we performed a comparison of RAP biomass and bare ground products with field-collected data provided by the Santa Ana Pueblo DNR using linear regression models. This data analysis was conducted in R. We also ran linear regression models and calculated the slope, intercept,  $R^2$ , and p-values to explore the alignment between RAP predictions and field observations across all years. This provided a general assessment of RAP's predictive strength. It's important to note that RAP estimates biomass production, meaning biomass growth over time, whereas the field data reflects standing biomass or what's currently on the ground. This difference may affect the precision of RAP's estimates. By comparing herbaceous biomass production and bare ground percent cover values from RAP with those measured in the field, we identified patterns of agreement or systematic biases. The overall regression results indicated how much variance in field data could be explained by RAP predictions, establishing a baseline understanding of RAP's performance.

To further explore potential temporal variability, we conducted year-by-year regressions. These models allowed us to assess how RAP's performance fluctuated across individual years, capturing potential environmental effects such as drought. We then analyzed each year's regression separately to determine whether RAP predictions aligned more closely with field data in some years than others.

#### ***3.3.2 Summary of Rangeland Trends***

We imported the annual biomass production and bare ground percent cover RAP data into R and aggregated it by range unit for each year of the study period. For each range unit, we summarized RAP TIFF files annually to calculate mean, minimum, and maximum values for biomass and bare ground, ensuring consistent year-over-year trend comparisons in productivity and ground cover. We used linear regression models to examine production trends over time within each range unit, quantifying shifts in bare ground cover. To capture variability in productivity, we calculated additional statistical measures for each parameter, providing insight into central trends and fluctuations over the study period. Finally, we created temporal profiles for each range unit to visually represent trends in biomass and bare ground cover.

#### ***3.3.3 Analysis of Bare Ground Trends pixel by pixel in Santa Ana Pueblo***

We used the Generate Trend Raster tool in ArcGIS Pro to evaluate pixel-level trends on bare ground raster data spanning 1985 to 2023. We explored different analysis parameters using the Generate Trend Raster tool, and then conducted a linear, harmonic, and Mann-Kendal trend analysis. These results were very similar and due to the linear models used for the other objectives of our study we chose to move forward with the linear trend analysis. We generated layouts in respect to our study area to visualize how pixels have changed over the study period. We tuned parameters that provided a multidimensional raster built on five bands as follows: slope, intercept, Root Mean Square Error (RMSE), R-Squared ( $R^2$ ), and the p-value. We inspected changes in pixels using a raster which was a combination of the five bands, then extracted singular bands to judge their respective contribution to the analysis. We created scatter plots, histograms, data summaries, temporal and spectral profiles to further analyze data.

## 4. Results & Discussion

### 4.1 Analysis of Results

#### 4.1.1 RAP vs. Field Data Correlation for Biomass and Bare Ground Cover

The comparison of RAP data with field data revealed significant differences in the accuracy of RAP's estimates for biomass production and bare ground percent cover. RAP biomass production estimates showed limited alignment with field data, with only 13% of the variation explained ( $R^2 = 0.13$ ,  $p < 0.01$ ; Figure 2). RAP consistently overestimated biomass production relative to field-measured standing biomass, highlighting a discrepancy likely driven by differences in measurement focus. RAP estimates biomass production rather than current standing biomass, as field-based clipping estimates measure. In contrast, for bare ground percent cover, RAP demonstrated a strong positive correlation with field observations, explaining approximately 67% of the variation in field data ( $R^2 = 0.67$ ,  $p < 0.01$ ; Figure 3). However, RAP tended to underpredict bare ground percentages, suggesting that while reliable for capturing trends, its estimates may be low, particularly at locations of higher bare ground cover.

Stratifying the data by year further clarified the relationship seen between RAP and field data in our initial models. For bare ground cover, individual years exhibited varied correlation strengths, with  $R^2$  values ranging widely from 0.31 to 0.85, though hosting consistently significant p-values ( $p < 0.01$ ). This range highlights that bare ground performance can vary considerably year-to-year but was ultimately reliable overall. Including precipitation data for the years tested revealed that bare ground estimates tended to perform better in drier years, where precipitation levels were below average. In comparison, biomass estimates showed weaker relationships across all years, with  $R^2$  values of 0.07 and 0.09 in 2015 and 2010, respectively ( $p < 0.01$ ). These results emphasize the robustness of RAP for bare ground monitoring while underscoring the necessity of field validation for biomass data.

Over the past 20+ years, drought conditions have significantly influenced bare ground cover, herbaceous biomass production, and annual precipitation trends in the study area. The chart reveals a general decline in annual precipitation over time, with notable drought years such as 1989, 1995, 2003, 2012, and 2020 characterized by significantly below-average precipitation levels. These drought periods correspond to increased bare ground cover percentages and reduced herbaceous biomass production, suggesting that water availability strongly influences vegetation dynamics. Despite some wetter years scattered throughout the timeline, the overall trend indicates increasing aridity, further emphasizing the need for adaptive land management strategies to mitigate the impacts of prolonged drought.

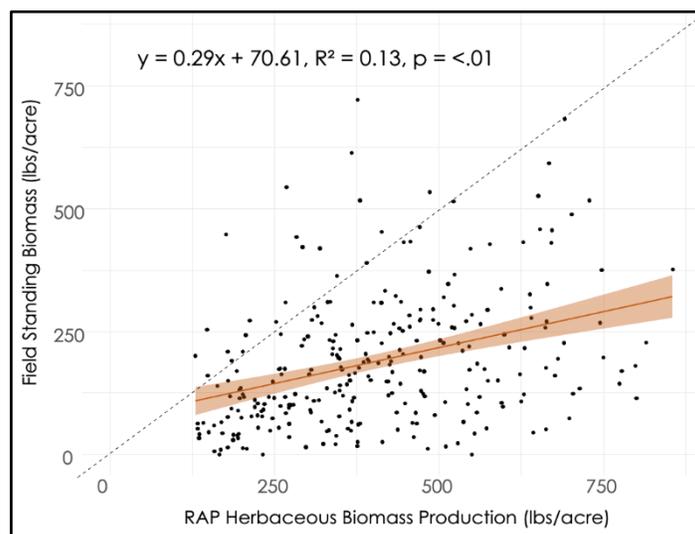


Figure 2. Relationship between field data and RAP biomass.

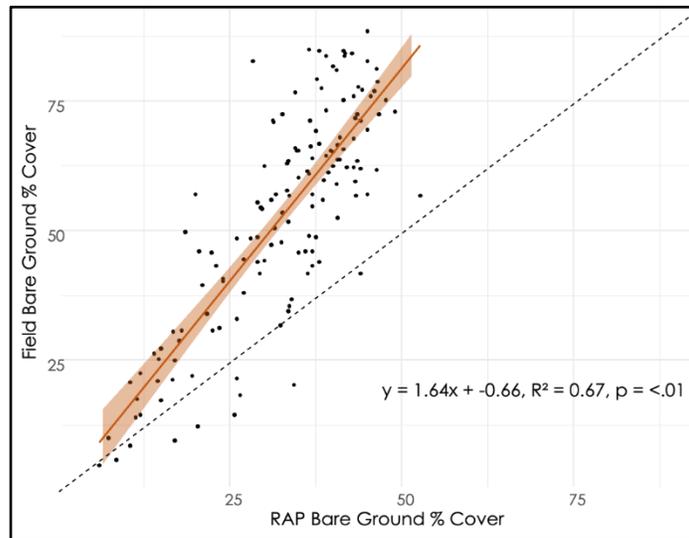


Figure 3. Relationship between field data and RAP bare ground cover.

#### 4.1.2 Trends in Bare Ground Cover (1985–2023)

The analysis of RAP data over nearly four decades revealed stable or declining bare ground cover trends across most of Santa Ana Pueblo’s rangelands. High interannual variation was observed in all pastures, with peaks aligning with drought periods. Peaks and troughs in bare ground cover and herbaceous biomass production often coincided with fluctuations in precipitation, particularly during notable drought periods (e.g., the early 2000s and early 2010s). These patterns suggest a strong relationship between precipitation and both bare ground cover and biomass production, emphasizing the significant role of climatic variability in shaping rangeland conditions (Figure 4). It is also important to note that these pastures differ in numerous factors beyond management, including variations in soils, geology, climate, vegetation type, and management history.

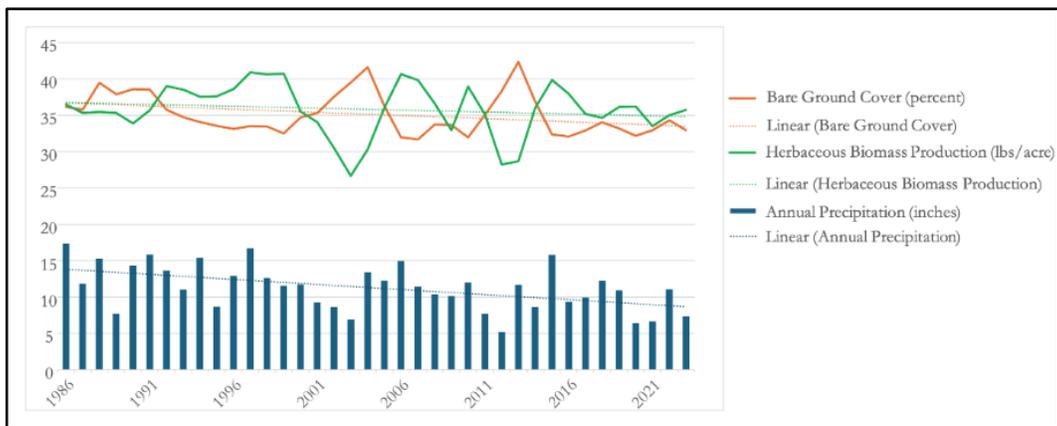


Figure 4. RAP bare ground cover percent, herbaceous biomass production, & annual precipitation over time.

Kwii Kee Nee Puu, acquired by Santa Ana Pueblo in 2015, showed a negligible slope of -0.04, indicating a minimal change in bare ground cover over time ( $R^2 = 0.02$ ,  $p = 0.43$ ; Figure 5). This limited change reflects its history as a working cattle ranch before acquisition and the different long-term management strategies employed compared to those used by the DNR in the Santa Ana Pueblo area. In contrast, Santa Ana Pueblo exhibited a more substantial slope of -0.13, reflecting a significant downward trend in bare ground cover, with time explaining 24% of the variation ( $R^2 = 0.24$ ,  $p < 0.01$ ). The steeper slope for Santa Ana Pueblo highlights its moderate improvement in bare ground cover, likely linked to effective management practices since the

start of the study period. These differences provide valuable insight for ongoing monitoring and future strategy development in both areas.

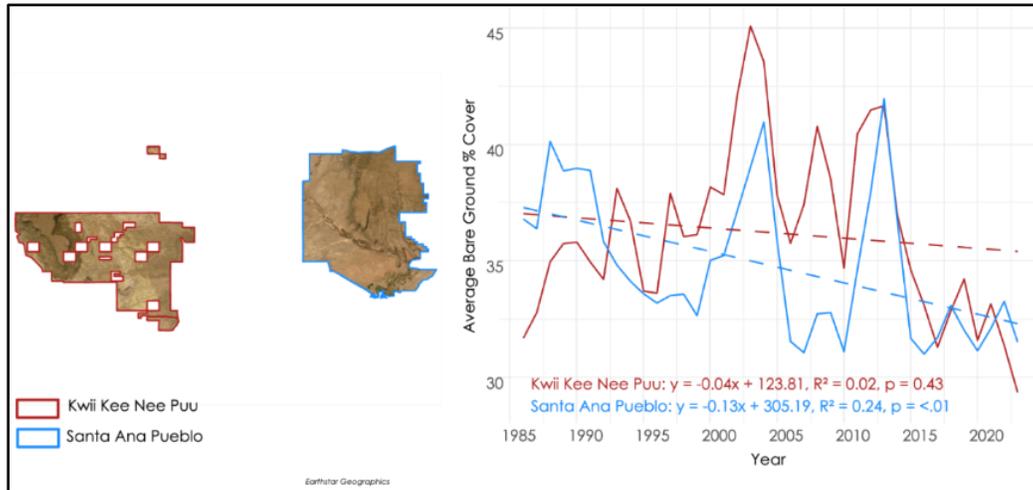


Figure 5. Bare ground trends over time, Santa Ana Pueblo vs. Kwii Kee Nee Puu.

Grazing Area 3 demonstrated the steepest decline in bare ground cover, with a slope of -0.27, indicating the highest magnitude reduction over time, although it still maintained the highest bare ground percentage. The Drought Relief and Wildlife zones also exhibited downward trends, with slopes of -0.15 and -0.17, respectively, showing modest reductions in bare ground cover that were statistically significant ( $p < 0.01$ ). In contrast, Grazing Areas 1 and 2 had much smaller slopes of -0.02 and 0.02, respectively, reflecting minimal changes in bare ground over the study period, with insignificant p-values and stable cover percentages. These findings highlight varying trends in bare ground reduction across different management areas.

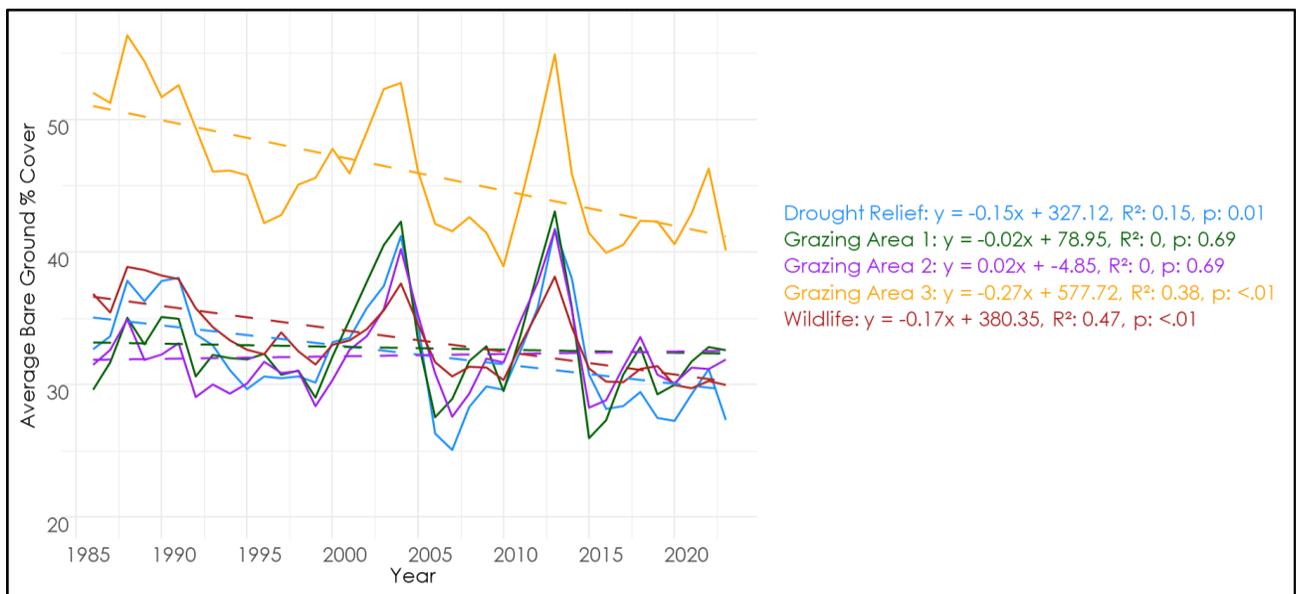


Figure 6. Bare ground trends over time, across rangeland units of different management types.

#### 4.1.3 Pixel-Level Analysis of Spatial Trends

The pixel level analysis is of great value because it provided maps that were utilized to compare a number of activities in Santa Ana Pueblo. The finer scale trends analysis highlights areas in Santa Ana Pueblo that underwent an increase, stability and decrease in bare ground cover over the years. We picked a few case

studies to compare our findings against previous rangeland efforts within the study area. Within juniper reduction zones, bare ground cover generally showed increases over time, reflecting the impact of juniper removal on soil exposure (Figure 5). These increases were largely contained within the designated areas, with surrounding regions generally exhibiting stable or decreasing trends. Along the Rio Grande riparian area, we observed significant decreases in bare ground cover (Figure 6), driven by the stabilizing influence of consistent water access on vegetation growth. Alongside these trends we also see areas along the river where bare ground has dramatically increased over time, likely reflecting the formation of new sand bars. This is a critically important process for establishing new cottonwood seedlings. Also relevant in these findings is the ongoing work of the DNR in riparian and cottonwood restoration projects which is a potential driver of these trends as well. These patterns underscore the importance of management actions and natural hydrological features in driving cover vegetation trends.

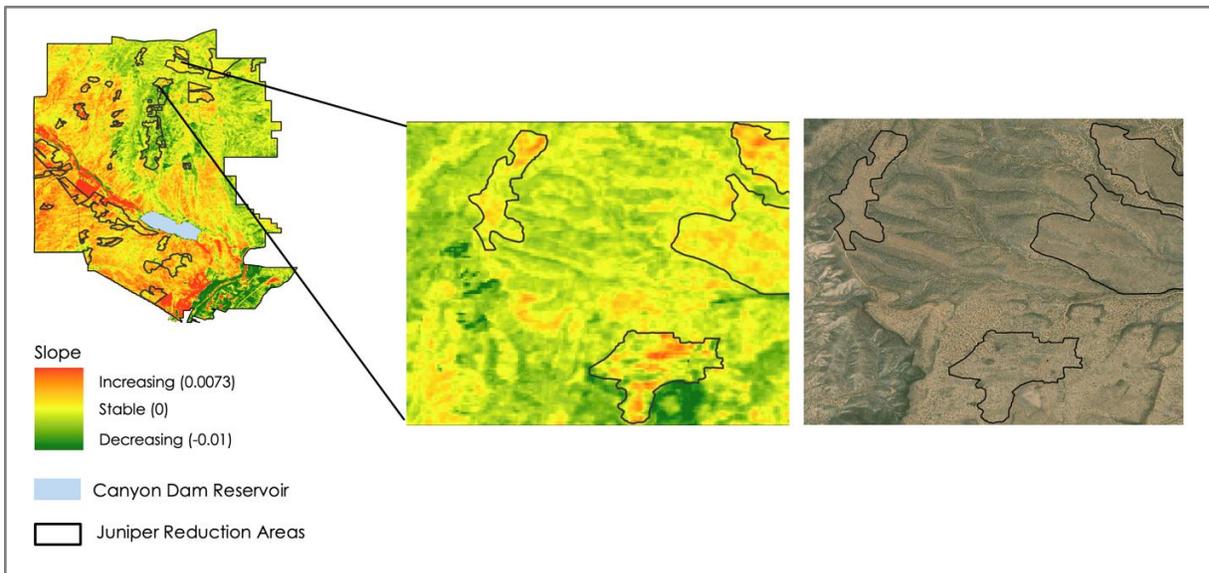


Figure 7. Trends in bare ground cover from 1985–2023 by pixel – Juniper Reduction Areas.

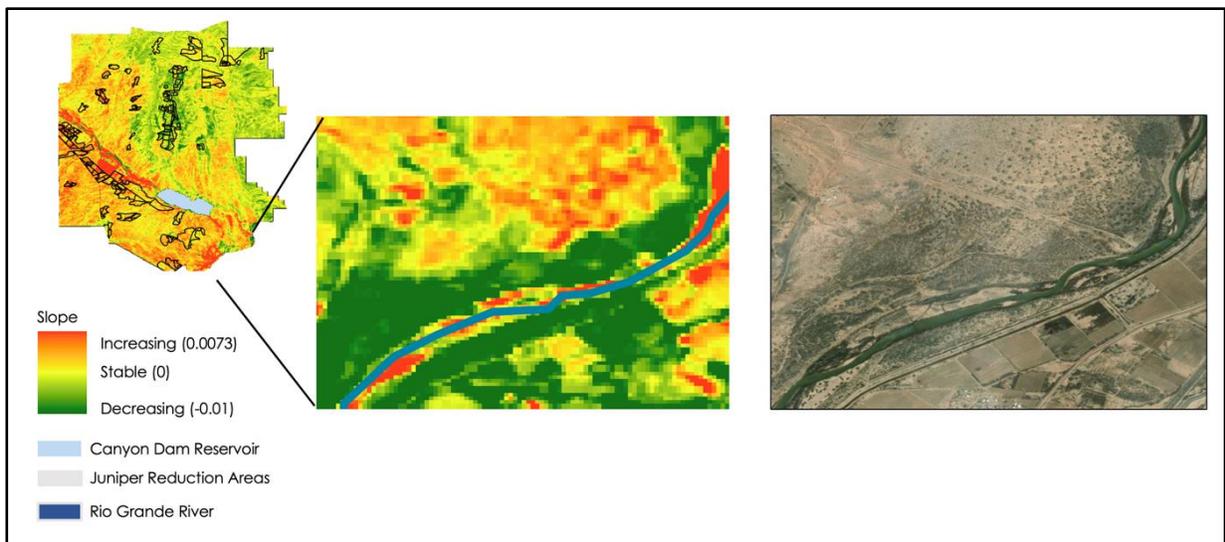


Figure 8. Trends in bare ground cover from 1985–2023 by pixel – Case study #1: Riparian Area

Wildlife areas which have no to minimal livestock grazing showed predominantly stable bare ground cover over time, with minimal regions experiencing significant increases or decreases. Grazing areas exhibited

greater variability, reflecting the dynamic nature of land use practices, including adaptive grazing management. Areas with notable decreases in bare ground cover highlight the potential for vegetation recovery and regrowth in managed landscapes.

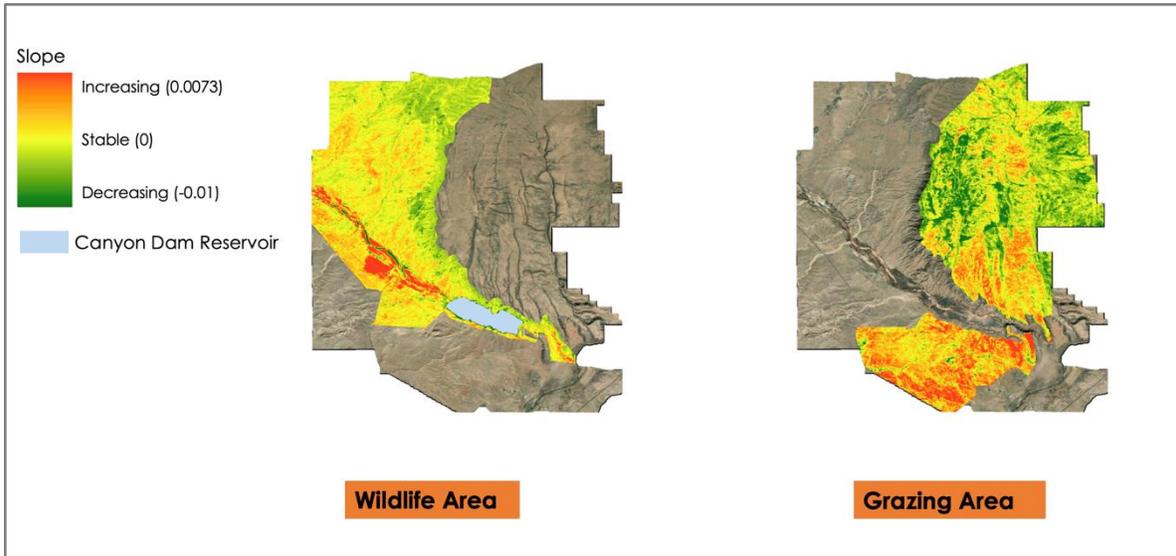


Figure 9. Trends in bare ground cover from 1985–2023 by pixel – Wildlife Area and Grazing Area

## 4.2 Limitations & Uncertainties

### 4.2.1 Multifaceted Drivers of Rangeland Dynamics

Disentangling the effects of management practices, climate variability, vegetation type, soil characteristics, historical land use, and inherent remote sensing errors presents a significant challenge. These interconnected factors contribute to the complexity of interpreting patterns and trends, underscoring the difficulty of isolating individual drivers of change. This theme is central to the broader narrative of our study highlighting the need for nuanced approaches to understanding rangeland dynamics and decision-making processes. In future work, evaluating RAP performance by vegetation type could provide valuable insights into these dynamics, offering a pathway to refine analysis and improve model applicability.

### 4.2.2 Temporal Variability

Year-to-year variability in RAP data accuracy introduces uncertainty into trend analyses. While RAP generally aligned well with field data for bare ground cover, variations in environmental conditions such as drought affected the strength of these relationships. The inclusion of long-term data mitigates this variability, but annual fluctuations should be considered when interpreting short-term trends.

## 5. Conclusion

### 5.1 Interpretation of Results

The integration of RAP data with Santa Ana Pueblo’s existing field monitoring practices provided valuable insights into the utility of NASA Earth observations for rangeland management within the Pueblo. The biomass estimates of RAP faced challenges in this study area, the limited correlation between RAP biomass data and field measurements highlights this limitation, indicating that RAP may not fully capture the nuances of arid rangeland biomass dynamics. These discrepancies emphasize the need for supplementary field validation to refine biomass monitoring in similar environments. RAP data demonstrated strong alignment with field measurements for bare ground cover, showing its potential to enhance long-term monitoring capabilities across the Pueblo’s rangelands. This alignment supports the DNR’s goals of sustaining regenerative practices by offering a reliable, broad-scale tool for tracking ecosystem health, particularly in areas impacted by interventions such as juniper reduction and rotational grazing. However, RAP’s biomass

production estimates did not correlate as strongly with field data, emphasizing the continued importance of field-based validation for accurate biomass monitoring in this arid environment.

The observed trends in generally stable or decreasing bare ground cover through a droughty period suggest that the DNR's current management practices, such as adaptive managed grazing, have had positive effects on ecosystem stability and resilience. The additional historical context provided by RAP, with data extending back to 1985, supports a deeper understanding of long-term trends that may not be immediately observable through short-term field studies alone. Furthermore, further interpretation of these spatial and temporal trends in bare ground would be enhanced through greater integration with Pueblo's knowledge and observations.

### ***5.2 Feasibility & Partner Implementation***

RAP data offers a feasible and useful supplement to Santa Ana Pueblo's existing field-based monitoring and geospatial analyses, aligning well with the DNR's goal of managing over 140,000 acres of rangelands sustainably. By incorporating RAP's consistent and extensive dataset, the DNR can potentially streamline aspects of its monitoring processes, gaining broader insights into ground cover trends across large areas and across time. This could aid in evaluating the impacts of interventions like changes to grazing management and juniper reduction treatments, adding a layer of long-term, spatially comprehensive data to support adaptive management practices.

However, the limited accuracy of RAP biomass data highlights an area where caution is warranted, particularly in regions with sparse vegetation or high soil reflectance. RAP can provide preliminary insights into biomass trends, but field data remains crucial for precise measurements. This reinforces the importance of using RAP as a complementary tool rather than a standalone solution, especially in areas where specific, quantitative biomass data is essential.

Ultimately, the integration of remote sensing with existing TEK and geospatial tools can support the DNR's commitment to sustainable land stewardship, helping to address challenges such as drought and overgrazing with a balance of traditional practices and advanced technology. The additional layer of remote sensing data enhances the DNR's capacity for adaptive management and supports their mission to protect, preserve, and enhance the natural resources of Santa Ana Pueblo for future generations.

### ***5.3 Suggestions for Future Work Involving Tribal Nation Rangelands***

There is now a global movement to strengthen and enhance research by bringing the best of Western and Indigenous sciences together to allow for more data-enriched studies (Wilcox, 2024). While the work we conducted primarily utilized a Western scientific construct, the critical importance of Santa Ana Pueblo's traditional Indigenous knowledge and data should not be overlooked. Utilizing culturally appropriate aspects of their scientific systems throughout all stages of the research process would undoubtedly create a more comprehensive understanding of rangeland ecosystem health. Incorporating these elements into future project design regarding tribal nation rangelands would serve to strengthen further collaborative work. If our tribal nation partners wish to work collaboratively in this fashion, traditional rangeland practices should be considered and incorporated into these findings to ensure the data is as useful as possible.

## 6. Acknowledgements

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### Advisors:

- Tony Vorster (Colorado State University, Natural Resource Ecology Laboratory)
- Nicholas Young (Colorado State University, Natural Resource Ecology Laboratory)
- Dr. Paul Evangelista (Colorado State University, Natural Resource Ecology Laboratory)
- Dr. Catherine Jarnevich (USGS, Fort Collins Science Center)
- Christopher Tsz Hin Choi (Colorado State University, Natural Resource Ecology Laboratory)

### DEVELOP Center Lead:

- Truman Anarella (Colorado – Fort Collins)

## NASA ACRES

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## 7. Glossary

**Adaptive management** – A flexible approach to managing natural resources by testing strategies, learning from outcomes, and adjusting actions as needed.

**Bare ground** – Land surface with minimal or no vegetation cover, exposed to erosion and environmental impacts.

**Clip-plot data** – Vegetation sampling data collected by clipping and weighing plants within defined plots to estimate biomass.

**Cloud computing** – The use of remote servers hosted on the internet for data storage, processing, and analysis, instead of local systems.

**GIS modeling** – The use of Geographic Information Systems to create, analyze, and interpret spatial models for understanding geographic phenomena.

**Intercept** – In linear regression, the value of the dependent variable when all independent variables are zero; the point where the regression line crosses the y-axis.

**Landsat 5 TM** – A satellite sensor (Thematic Mapper) operational from 1984–2013, capturing multispectral imagery for earth observation.

**Landsat 7 ETM+** – A satellite sensor (Enhanced Thematic Mapper Plus) operational since 1999, providing high-resolution multispectral imagery with improved calibration.

**Landsat 8 OLI** – A satellite sensor (Operational Land Imager) operational since 2013, delivering advanced, high-quality multispectral and thermal imagery.

**Landsat 9 OLI-2** – A satellite sensor operational from 2021, an upgraded version of the Operational Land Imager for enhanced earth observation.

**Line point intercept-transect data** – Vegetation data collected by recording plant species and ground cover types at fixed points along a transect line.

**Linear regression models** – Statistical models that establish a relationship between a dependent variable and one or more independent variables using a straight-line equation.

**Machine learning** – A method of data analysis that uses algorithms to identify patterns and make predictions or decisions without explicit programming.

**Multidimensional raster** – A data format representing multiple layers of spatial information, often used to analyze temporal or spectral variability across a grid of pixels.

**NASA Earth observations** – Satellite-based data collected by NASA to monitor and analyze Earth's systems, such as land, atmosphere, and oceans.

**P-value** – A statistical metric indicating the probability of obtaining the observed results assuming the null hypothesis is true; used to assess the significance of findings.

**Photo-point monitoring** – A method of tracking environmental changes by repeatedly photographing the same location over time.

**Rangeland habitats** – Ecosystems dominated by grasses, shrubs, or open woodlands, primarily used for livestock grazing and wildlife habitat.

**Rotational Grazing** - A livestock grazing practice where animals are moved between different paddocks or grazing areas in a planned sequence to allow vegetation in previously grazed areas to recover and regenerate.

**R<sup>2</sup> (Coefficient of determination)** – A statistical measure that indicates the proportion of variance in the dependent variable explained by the independent variables in a regression model.

**Slope** – In linear regression, the rate of change in the dependent variable per unit changes in the independent variable, represented by the coefficient of the independent variable.

**Traditional Ecological Knowledge (TEK)** – (also commonly referred to as “Indigenous Knowledge” or “Traditional Indigenous Knowledge”.) TEK refers to the unique scientific systems developed and utilized by Indigenous peoples worldwide. It is commonly sought to provide a more holistic understanding of the earth and its ecosystems into mainstream society.

**Western geospatial technologies** – Tools like GIS, remote sensing, and GPS, developed through Western scientific methods to collect, analyze, and visualize spatial data.

## 8. References

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