Land Use Regulations on Sensitive Habitats (e.g., barrens) in Colorado

(Credit Colorado National Heritage Program)

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ESS 440: Practicing Sustainability Capstone

Spring 2025

Executive Summary

The state of Colorado is home to a wide array of ecosystems, each with distinct flora and fauna that characterize their presence. Barrens, specifically, are rocky habitats with mostly shale or limestone sediment, alkaline soils, and minimal plant cover which makes these ecosystems drastically different than the state's typical landscape. The Colorado Natural Heritage Program (CNHP) monitors the state's rare and imperiled species and habitats to promote the conservation of Colorado's valuable biological resources. Our ESS 440 Capstone Group has been tasked with developing a classification workflow for barrens to aid in the protection of these vulnerable ecosystems. With pressure from oil and gas industry expansion, it is pertinent that the 2025 State Wildlife Action Plan (SWAP) includes a clear definition and identification method to ensure uniform understanding across the board in terms of ineligible land for drilling and fracking. Due to the chemical structure, disturbance on barren topsoil has the potential to leach pollutants into local waterways and pose serious health risks to the surrounding wildlife. Thus, with help from CNHP's existing data and other researched layers, a replicable model for identifying barrens has been initialized to strengthen protection efforts and guide conservation priorities. While our group did face a few major challenges throughout the project, we hope our model will assist policymakers as they determine where oil and gas companies can continue extracting resources in Colorado.

Introduction

Barrens are rare, nutrient-poor ecosystems with unique plant and insect communities making them highly sensitive to disturbance. The Colorado Natural Heritage Program has proposed restricting oil and gas drilling in these areas, aiming to regulate the protection of these landscapes. The Colorado Energy and Carbon Management Commission (ECMC) currently adheres to conservation measures in line with the 2015 Colorado Parks and Wildlife State Wildlife Action Plan which recognizes the significant risks oil and gas development pose to barren landscapes (Colorado's ECMC, 2024).

Within the extensive 417-page SWAP document composed of a highly detailed record of all Colorado's ecosystems and their current qualitative state of flora and fauna, barrens are reported to experience drastic changes when drilled and fracked for their oil reserves (Colorado's ECMC, 2024). Proposed regulations currently examine pre- and post-disturbance impacts with in-depth analysis to determine ecosystem health throughout the disturbance (Colorado's ECMC, 2024). Environmental impact assessments help predict these effects, aiming to minimize ecological damage before development begins (Colony Development Firm, 1974). While drilling inevitably alters ecosystems, understanding the extent of this disruption is crucial for protecting both the land and surrounding ecological communities (Knee, 2019).

The CNHP emphasizes expanding protections of barren landscapes as they support endemic species that maintain ecosystem health (CPW, 2015). Drilling and fracking exponentially increases the risk of toxic elements within barren soils leaching into nearby water tables, threatening both environmental and human health. As pressure grows to increase resource extraction, safeguarding barren ecosystems against human disturbances ensures this fragile ecosystem is not lost or heavily degraded before we can thoroughly study its services and ecological benefit towards wildlife.

Harmonious with the upcoming SWAP renewal, expected to be finalized later this year, the CNHP has made it their goal to spotlight barren habitat classification and external influences. Tasking our cohort of students within the CSU Department of Ecosystem Science and Sustainability, 2025 Spring Capstone to generate a map of where barrens are likely to be found within Colorado, CNHP can then share this framework with other stakeholders like the ECMC or local oil and gas businesses for future reference in mitigating the impact of human activities on these ecosystems. The implementation of this map within the 2025 SWAP and ultimately the regulations that are passed by the ECMC will work to bridge the gap of its environmental protection while supplying necessary boundaries for oil and gas industry expansion.

What are Barrens?

As previously mentioned, barrens are ecologically unique landscapes that form on exposed layers of sedimentary rock often dating back to the Cretaceous period (Rondeau, 2009). Shaped by erosion, uplift, and other geological forces, these areas are defined by their thin, mineral-rich, and alkaline soils with little to no organic matter resulting in frequently absent O soil horizons (Silva & Ayers, 2016). The rocky surface typically resembles fractured pavement, with scattered shale fragments and sparse clumps of vegetation (Decker & CNHP, 2007). Barren landscapes experience extreme conditions including intense solar radiation, slow water infiltration, and compacted soils (Potter 1985). Since barrens are primarily composed of shale and limestone, the surface has moderate to low permeability meaning water is absorbed at slower rates so a majority of precipitation is evaporated. As a result, total vegetation cover is typically below 25% and dominated by drought-tolerant bunchgrasses, hardy shrubs, and highly specialized species that have evolved to survive in nutrient-poor soils with metal substrates (US Geological Services, 2017).

In the state of Colorado, barrens are part of a diverse ecological gradient spanning from high alpine ponderosa forests in the west to semi-arid shortgrass prairies in the east (National Parks Service, 2024). They frequently overlap with other land types that visually look very similar, such as rocky outcroppings and the highly erodible badlands (Martínez-Murillo, 2018). Though they may lack aesthetic appeal, barrens are important ecosystems that provide the necessary chemical structure for plants that thrive in selenium- and nickel-rich soils (CNHP, 2009). Many of these species act as hyperaccumulators, concentrating heavy metals and reducing their deposition in adjacent soils (Colorado Parks and Wildlife, 2015).

All together, barrens are not easily defined by one clear-cut category which complicates both ecological understanding and regulatory classification. In the face of increased oil and gas exploration, particularly under shifting political leadership, clarifying the ecological status and conservation value of barrens becomes vital. These ecosystems are not just biologically important, they represent a critical decision point in balancing natural resource development with biodiversity preservation (University of Colorado Boulder, 2022).

Oil and Barrens

The oil and gas industry supplies consumers with an essential good that nearly every person around the world depends on today. In the United States, driving is ingrained in the culture with social norms that make it common for individuals to obtain a driver's license by age 16 and access to a vehicle by 18. Much of the crude oil that fuels this car centric lifestyle comes

from kerogen-rich rocks found in remote, barren ecosystems (Turgeon, 2023). However, fracking and drilling for oil can disrupt essential ecological functions in these sensitive areas (Wang, 2021). While the demand for crude oil is expected to increase over the next four years, setting clear boundaries for drilling eligibility could help bridge the gap between crucial conservation efforts and the continued expansion of the oil and gas industry (Wang, 2021).

The extraction of oil has significant environmental consequences, particularly for surrounding ecosystems, as oil and gas operations are one of the largest industrial sources of air pollutants (Stiffler & Jalali, 2023). Volatile organic compounds released from these activities decrease air quality and not only harms ecological health, but also poses risks to human well-being while diminishing recreational value. Cleaner air means fewer health risks and clearer skies for sightseeing, leading to the potential for increased recreation. In Colorado, where fracking is used in 95% of oil and gas wells (McDaniel, 2024), the environmental stakes are especially high. This technique utilizes about 80 thousand gallons of water per year, a worrisome fact in an arid, drought-prone state like Colorado (Stiffler & Jalali, 2023). Beyond water use, fracking also threatens water quality. A study in Pennsylvania from 2010 to 2013 linked 116 contaminated wells to fracking activities (Jackson et al., 2014). Additionally, houses in close proximity to oil and gas wells are often devalued, especially on the western slope, where a 35 percent decrease in value has been seen in properties within a mile of oil wells (Stiffler & Jalali, 2023). Given these wide-ranging environmental, health, and economic consequences, it becomes even more critical to identify and protect vulnerable ecosystems before further development occurs.

Project Overview

Our ESS 440 Capstone Group has partnered with the Colorado Natural Heritage Program to create a replicable framework and comprehensive map of barren ecosystems across Colorado. To the untrained eye, these systems can easily appear as ordinary, ecologically insignificant plains, making them seemingly ideal sites for oil and gas development as people may think they are doing no harm due to the lack of visible flora and fauna. Due to this, detection and effective mapping of these systems are vital to inform developers where these systems are and how to avoid them.

This task is easier said than done and requires a thorough understanding of what makes these ecosystems so unique. To better understand the distinguishing factors of barren landscapes, our group created a variety of remote sensing products ranging from land cover classifications to single-band reflectance wavelengths. Special emphasis was placed on two key

datasets, LANDFIRE and SWAP, as recommended by our project partner. LANDFIRE datasets were used to create a masking layer and validate model outputs while SWAP mapping products were used to evaluate what improvements needed to be made for future map iterations. Both of these products will be assessed using a random forest model trained on supervised ocular cover classifications. This model will help predict the likelihood that unclassified areas represent barren landscapes. Through this process, our group aimed to highlight the distinct characteristics of barrens in a way that enables confident, scalable detection and mapping.

GIS Methods

When creating the final model, we first needed to implement a random forest land cover classification model to produce a mapping layer for barren ecosystems across Colorado. Our group's CNHP advisor then provided us with areas that were already known to be barren ecosystems. In order to train the model, our group manually classified ocular polygons, identifying areas as either present (barren ecosystem) or absent (other ecosystem). This can be seen in the Figure 1, which showcases areas of barrens (green) and non-barrens (red).

Next, each polygon was assigned a set of random points so remote sensing data could be extracted at varying locations. These points, along with their corresponding data, were used to train and validate our random forest model. Lastly, we applied a grid system over our study area and followed a similar random point approach to determine the dominant pixel classification in each grid cell, which was then mapped in our final product.

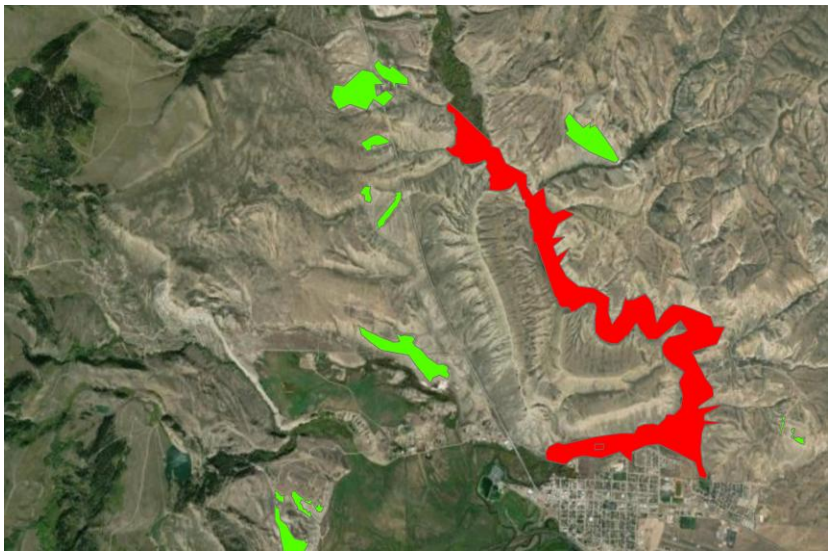

Figure 1. Image of Ocular Polygon Classification. Barren systems are selected in green and non-barren systems are selected in red.

Challenges

During this process, the group encountered multiple barriers. The biggest challenge was that Google Earth Engine, where we initially started this process, did not have enough computing power to efficiently run the model with run times estimated to be over twelve hours. This led us to rewrite our model in R during the later stages of our project timeline. We also ran into problems with our model overestimating the number of barrens present in our spatial extent. As seen in Figure 2, our beginning model outputs were greatly over-predicting barren ecosystems, incorrectly including plain habitats as a part of barren habitat (red is barren, blue is absent). This is due to training data that did not include enough absence polygons in short grass prairie ecosystems, leading the model to misidentify those areas as barren. To help fix the issue, the group drew over 400 more absence polygons and adjusted the masking layer to remove areas that are known non-barren systems. Additionally, the final output was adjusted to a finer resolution to provide more accurate predictions.

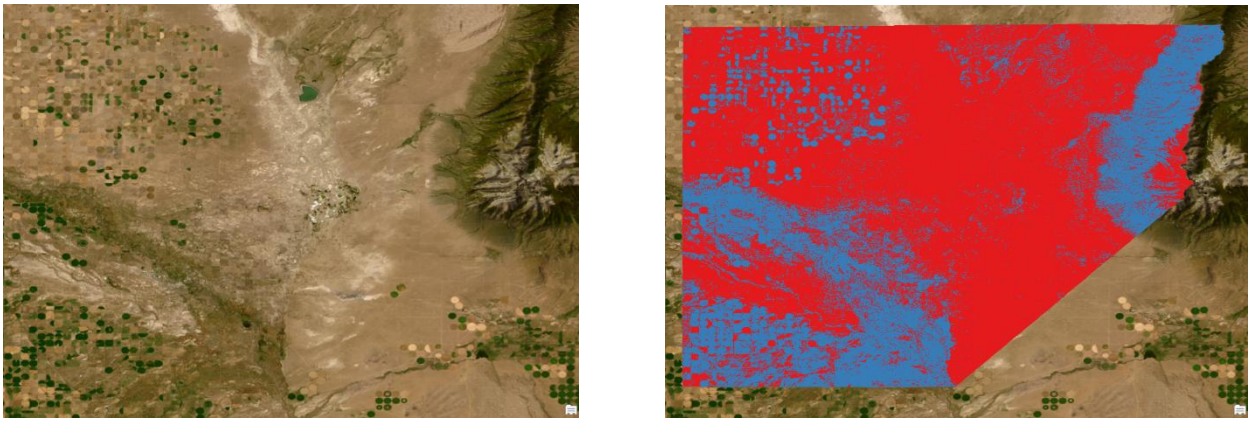

Figure 2. Model Predicted Barren Area in Alamosa County, Colorado. The left image is the county, with white areas being barren ecosystems, while the right showcases over prediction, with red being barren and blue being non-barren.

After these issues had been accounted for, we then ran into problems processing large amounts of data in ArcGIS Pro. Many of the tools we ran in this software were unable to process more than approximately 5 million inputs, prompting our model to generate outputs for only sections of a county which is depicted in Figure 3. Future iterations of this workflow can divide counties into multiple subsections to achieve more success with output completion.

Figure 3. Model Predicted Barren Area in Moffat County, Colorado. The lower half of this image shows a successful model classification with blue areas being classified as barren. The upper half of this image shows a series of absent classification values, which likely indicate that ArcGIS Pro was unable to process all of our classification values.

Takeaways for Our Stakeholders

The Colorado Natural Heritage Program asked our ESS 440 Capstone Group to develop a workflow for classifying barren ecosystems across Colorado. Throughout this process, we encountered unexpected challenges including limited software capability and little time for model refinement. Moments like these illustrate the complexity of statewide classification for barren ecosystems and highlights the importance of this project due to the level of detail required for accurate identification. Despite the setbacks we faced, our work provides a strong foundation for future progress and modeling of barren habitats within Colorado.

Our group classified, assessed, and processed a large range of spatial data, outlining a replicable workflow that CNHP may now use as a launching point for the updated 2025 State Wildlife Action Plan. Although we were unable to generate final county-level maps due to repeated ArcGIS Pro crashes, the structure of our model offers a valuable baseline for those continuing this work. Given more time, research, and hindsight, we would have focused on refining model parameters by creating more absent polygons in brown fields and low prairies. We also would have established more quality control checks when creating ocular classifications to ensure accuracy in outputs. Our group hopes that CNHP will be well-positioned to expand upon our initial efforts, whether through testing alternative classification techniques, improving spatial resolution, or scaling up outputs. Ultimately, this project marks the beginning of a

broader initiative where CNHP can leverage the tools and workflow our group generated to build a comprehensive, long-term solution for mapping barren ecosystems throughout Colorado.

Next Steps Forward

With contemporary legislation restricting oil and gas extraction on barren landscapes, a clear and concise definition of how these ecosystems are classified is crucial to successful implementation. Additionally, there needs to be a uniform definition of what exactly a barren habitat is, as enforcement of such conservation legislation may be inconsistent with critical habitats overlooked and disturbed. Without a clear definition, there also leaves room for public and stakeholder mistrust, as some may see restricting extraction on a habitat that lacks a clear definition more controversial. Our semester-long project, and the barriers we encountered, calls for a replicable, accurate mapping process that requires less run times and processing power in order to make the product accessible to users. By making a process that is replicable and accessible, we can help policy makers and experts identify large-scale, or even statewide, barren ecosystems in their own areas. This model could be further used in future conservation efforts, to analyze and map other threatened ecosystems.

Furthermore, we want to highlight an important regulatory gap that was recognized during our initial research and data collection stages. While the Colorado Natural Heritage Program hopes Colorado Parks and Wildlife will include banning of drilling and fracking on barren ecosystems in the 2025 State Wildlife Action Plan, fracking is still permitted on these landscapes under current policies. This raises valid environmental concerns regarding habitat integrity and ecosystem resilience in which our project responds to by creating the framework for a replicable mapping process. While we were not able to create a cohesive map of barren ecosystems through our ocular classifications, our group manually observed barren ecosystems across the state. A more in depth model is required to map barrens as they are geographically small and sporadic, meaning extra precautions should be taken to avoid these landscapes since they may not be self-evident in all geographic areas. Colorado's government structure further emphasizes the need for this project relative to current legislation as multiple entities are expected to mitigate the impact of oil and gas extraction. A written classification process with a supplemental mapping framework will help strengthen the argument that barren ecosystems must be protected in order to achieve agreement across Colorado's government and within agencies.

Despite the challenges we encountered, including limited time for model refinement and repeated software crashes in ArcGIS Pro during the final mapping stage, our project helps lay

the groundwork for future efforts to map barren landscapes in Colorado. While we were unable to fully implement or finalize the maps at a county level, the preliminary analyses we produced establish a valuable framework for continued development. Moving forward, we strongly recommend prioritizing quality control and assurance measures to ensure the reliability of any derived mapping. Ultimately, we see this project as a starting point for the Colorado Natural Heritage Program to build upon, refine, and expand in order to develop a comprehensive and accurate statewide map of barrens.

To safeguard Colorado's rare and fragile barren ecosystems, we urge policymakers to adopt and build upon our mapping framework while simultaneously closing the legal loopholes that allow fracking within these sensitive areas. Only with enforceable boundaries and comprehensive protections can we fortify the long-term resilience of barren ecosystems. We call on state agencies, conservation leaders, and fellow researchers to integrate this approach into broader land-use planning procedures and extend its application to other vulnerable landscapes across the nation.

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Appendix

A: StoryMap - [Building the Framework for Mapping Colorado's Barrens]

B: Google Drive - [Barren Detection Model]