Soil Comparisons in a Disturbed Chaparral Area: Evidence of Primary Succession

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Abstract

In 1996, the construction excavation of a mature chaparral area at Flintridge Sacred Heart Academy created a barren area named the Cut, stripped of previously present plants, nutrients, organic matter, and soil. Thirty years later, this area is slowly redeveloping and appears to be a stable community with sparse vegetation surrounded by chaparral and coastal sage scrub. The severe nature of the disturbance means that primary succession is most likely the successional pathway to recovery. This study focuses on the slow recovery of a disturbed chaparral ecosystem through soil and ecological analyses, including tests of nutrient levels, pH, organic matter content, clay composition, and root depth, while comparing the cut to the surrounding mature chaparral. Our results show that despite the disturbance, the Cut is undergoing slow primary succession. The key findings include depleted nutrients, regular pH, elevated clay and organic matter content, higher water retention, longer water infiltration, and shorter plant root depth, all in the cut, indicating characteristics of an area going through primary succession. This study confirms that chaparral ecosystems can recover from severe disturbances through primary succession, albeit at a slow rate. These findings underscore the importance of long-term monitoring to understand the trajectory of ecosystem recovery.

1.0 Introduction

Urban expansion has caused a loss of 50% of species richness worldwide, based on localized site surveys. (Li et al., 2022) This threat to species extends to California's beautiful native chaparral, which covers approximately six percent of the state (Syphard et al. 2019) and houses 24% of California's native plant populations (Halsey & Keeley, 2016). In addition, the deep root systems of chaparral plants are an important part of natural erosion control (Trautwein & Harris, 2015). Understanding how chaparral responds to disturbance is important for maintaining this vital ecosystem of California. This paper will give an overview of succession, discuss the importance of chaparral, and present the results of an ecological survey of a severely disturbed chaparral area along with showing how disturbance history and ecological context influence soil content.

1.1 Site History

Prior to 1995, the land northwest of Flintridge Sacred Heart Academy was an area of mature chaparral and oak forest (see Figure I). During the 1996 construction of a sports field and gym, the land was excavated (Figure II), with soil and rock removed. Today, thirty years later, the severely disturbed area ("the cut") has begun the process of recovery and can be easily compared to nearby mature chaparral (Figure III).

		
Figure I. *Flintridge Sacred Heart 1994*	**Figure II.** *Fintridge Sacred Heart* 1996-1997	**Figure III.** The CUT (triangle) and The Chaparral (rectangle) *Flintridge Sacred Heart 2024*

1.2 Classical Plant Succession Overview

Ecological succession describes how species and habitats in a terrestrial ecosystem change over time. Primary succession describes the changes from a starting point of barren land, while secondary succession happens after a major disturbance. The most significant difference between the two succession categories is in the starting soil; secondary succession begins with soils that have previously existed with plants and seeds, while primary succession begins with barren land.

1.3 Chaparral Characteristics- Overview of Biome, Auto Succession, and Soil

The Mediterranean-type climate, characterized by hot, sunny, and dry summers and cooler, wetter winters, includes chaparral, coastal sage scrub, oak woodlands, montane conifer forests, riparian woodlands, grasslands, and salt marsh ecosystems (One Earth, 2020). During the summer and early autumn, frequent fires appear in the chaparral biome and contribute to the chaparral's auto-succession transition, meaning that chaparral-specific species are still present after a disturbance and continue to dominate the area (Hanes, 1971). Autosuccession becomes the alternate pathway for the chaparral to reach a climax community, which is different from classical plant succession.

The chaparral soil is characterized as coarse, made up of broken-down geological material (U.S. Department of Agriculture, Forest Service, n.d.), of which around 85% is lithosols (rocky soils that contain most of the physically disintegrated igneous-metamorphic parent rock) (Storie and Harradine 1958). Typical chaparral soil pH ranges from 6.1-6.7 and fluctuates based on the seasons because of soil moisture and rainfall (Vourlitis, Pasquini, & Mustard 2009). These soils are relatively low in nitrogen, potassium, and phosphorus and susceptible to erosion. Erosion becomes accelerated when hydrophobic layers develop in the soil, which normally form after severe wildfires but can also develop in drier soils without disturbances (Parkes 2025). Water repellency decreases when precipitation occurs and soil moisture is constant (Hubbert and Oriol 2005). When water does penetrate the soil surface, it drains rapidly because of the soil's pore size, which shows little water-holding capacity. Because of the low nutrient and water availability, vegetation that thrives in the chaparral must adapt to these limitations.

1.5 Literature Review

1.5.1 Understanding Chaparral Succession- Why the Chaparral is Different

Richard Vogl presented a manuscript at a conference in 1971 that highlighted a new way of thinking about chaparral succession. Vogl suggested that chaparral does not go through the stages of classical plant succession where new vegetation modifies a site. Instead, after a disturbance such as fire, fire-resistant, mature vegetation immediately dominates the area. Vogl mentioned that when the chaparral has been severely disturbed, often from long-term overgrazing, changes in the frequency of fires or landslides, he expects that the chaparral will not return to its original mature vegetation, culminating with Coastal Sage Scrub instead.

Vogl's observations suggest that chaparral does not need to rely on typical species replacement of secondary succession. Understanding how chaparral goes through succession differently compared to other ecosystems (site dominance for recovery) can help interpret ecological survey data in a disturbed chaparral ecosystem compared to mature chaparral vegetation.

1.5.2 Clay Content During Succession

In 2002, Lu, Moran, and Mansuel published a study on the Brazilian Amazonia secondary succession and its influence on soil properties. Two regions in the Brazilian Amazon that experienced deforestation were observed to identify the relationship between soil properties and succession. The two areas showed a decrease in clay content as the areas progressed into advanced secondary succession. In the first area, as secondary succession progressed, clay content decreased, potentially due to the leaching of particles from water movement and the growth of vegetation roots. Because of the second area's coarser composition, clay content decreased likely due to the coarse sand structure contributing to a rapid nutrient leach, leading to a loss of clay particles.

These results from both sites show that as succession progresses, the clay content in the soil will decrease. While this study compares soils and succession in the Amazon, the idea of a connection between clay content and successional stage in chaparral is worth exploring.

1.5.3 Organic Matter During Succession

Organic matter is a key component of soil health and ecosystem recovery, especially after extreme disturbances like landslides. Schomakers et al. in 2019, used s, organic carbon (OC) as a proxy for total organic matter because it's also a measurable component that makes up most of the organic matter content. The study specifically used soil organic carbon to track how organic matter content varies over time on landslide scars in the subtropical mountains of Taiwan. They looked at landslide sites ranging from 6 to 41 years old and they found that carbon, and therefore organic matter, built up slowly in the beginning, mostly because there wasn't vegetation yet. .

Once grasses were established, OC levels began to increase. When bamboo took over around year 15, recovery accelerated. By year 41, the sites reached about 64% of the OC found in undisturbed forest soils.

While the ecosystem in this study is subtropical and not chaparral, it offers insight into how organic matter is correlated to successional recovery after major soil disturbances such as landslides. Chaparral systems, which are drier and often slower to regenerate, are not expected to follow the same pace of recovery.

1.7 Driving Question and Project Statement

A southern California mature chaparral community at FSHA was excavated in 1997 to provide for the construction of an athletic field (Crane field). After construction, the excavated area surrounded by chaparral and oak woodlands remained. Today, nearly thirty years later, the once excavated land appears to be a stable community surrounded by chaparral and coastal sage scrub. Using this local event and subsequent succession as a model, we seek to understand the successional pathway of severely disturbed land surrounded by chaparral and oak woodlands. To address this question, an ecological survey including plant species and soil characteristics was initiated to compare an area of disturbance and adjacent mature chaparral. The focus of this paper is to understand soil characteristics, while the associated plant communities are being studied by other members of our group (Gamboa & Walsh). The severe nature of the disturbance means that primary succession is most likely the successional pathway. If so, a high clay and low organic matter content is expected, compared to mature chaparral.

2.0 Methods

2.1 Belt Transect and Quadrat Method

Quadrats	Region of Survey
Quadrat 1	Disturbed Area
Quadrat 2	Ecotone
Quadrat 3	Undisturbed Area
Quadrat 4	Pure Disturbed Area
Quadrat 5	Pure Undisturbed Area
Quadrat 6	Pure Undisturbed Area

Figure IV. Visual Representation of Surveyed Area and Quadrant Key

Quadrats 1, 2, and 3 (3 x 3 meters each) established a gradient from the disturbed area, through the ecotone, to the undisturbed area (chaparral). Quadrat 4 evaluated plants in the purely disturbed area, while quadrats 5 and 6 represented purely undisturbed areas (see Figure IV). Within each square sample plot, samples of soil were taken from the surface (top 10 centimeters of soil) and subsurface (between 10 - 25 centimeters) using a shovel. Soil samples from 1, 2, and 3 were taken, as well as Quadrat 4 in the pure disturbed area and Quadrats 5 and 6 in the pure undisturbed areas. In total, 12 samples were accumulated, two different depths of soil samples per quadrat. These soil samples were taken back to the lab and used for the nutrient and pH test, water retention test, LOI test, and soil sieving test. Water infiltration tests were completed on site, with one infiltration test per quadrat for a total of six infiltration tests.

2.2 Soil Tests

The pH soil tests use a standard pH scale and nutrient tests measure the amount of Phosphorus, Potassium, and Nitrogen in the soil using a scale of Depleted (level 0), Deficient (level 1), Adequate (level 2), Sufficient (level 3), and Surplus (level 4). The method used in this study was adapted from the Luster Leaf Rapitest Soil Test Kit. The full experimental methodology is found in Appendix 7.1.

A water retention test is used to determine the water holding capacity of soils. The method used in this study, adapted from the Soil Conservation Service (Foster, Fox, 1970), included pouring a known volume of water through a soil sample and recording the amounts captured by and passed through the sample. The full experimental methodology is found in Appendix 7.2.

Water infiltration tests are used to determine how fast water can soak into soil, and is related to run-off and erosion characteristics. The method used in this study, adapted from the Soil Conservation Service (Foster, Fox, 1970), includes pouring water into a cup in the field and measuring the time it takes for the water to leave the cup. The full experimental methodology is found in Appendix 7.3.

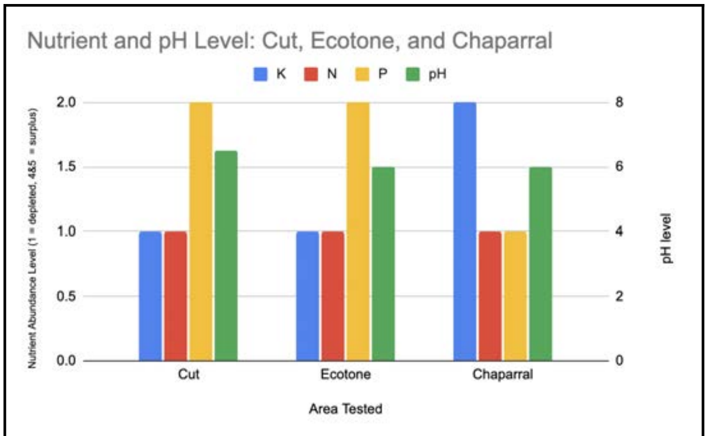
A sieving test is used to determine the overall soil composition. Specifically, it gives percentages for each size of particle found in the soil, like gravel, sand, silt, and clay. The method used in this study, adapted from Geoengineer (2022), includes pouring the dry soil sample into stacked sieves and measuring the mass percentage of soil that sits on top of each sieve mesh. The full experimental methodology is found in Appendix 7.4.

The Loss On Ignition (LOI) method is one of the most common methods used to measure a soil's organic matter content. LOI works by weighing pre-burnt soil, burning organic matter in the soil, and then measuring the post-burn soil weight loss to determine the mass of organic matter. A ceramic kiln was used to burn the soil, following a Simon Fraser University Soil Science Lab methodology (Robertson, 2011) since LOI does not have a universal standard protocol (Hoogsteen et al., 2015). The step-by-step methodology used is found in Appendix 7.5.

3.0 Results

3.1 Nutrients

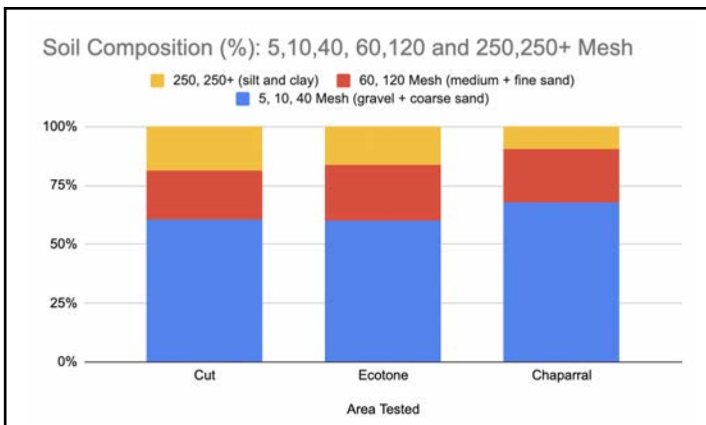
All areas show low nutrient levels, consistent with typical chaparral soils. The pH level is slightly acidic, also consistent with the typical pH range of chaparral soils.



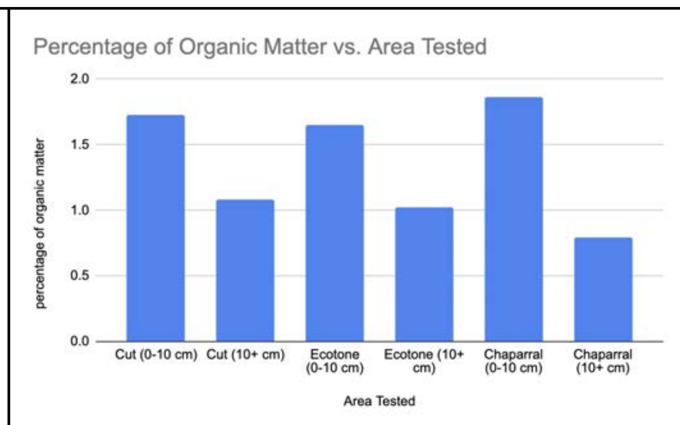
Graph 1: Potassium, nitrogen, phosphorus, and pH levels of all areas

3.2 Soil Composition and Organic Matter

Graph 2 shows soil particle size distributions. Particle sizes are smaller in the cut (more silt and clay) compared to the chaparral. Graph 3 shows the variation in organic matter. Chaparral has the highest level of surface organic matter (< 10 cm) but the lowest level of subsurface organic matter (10 - 25 cm).



Graph 2: Soil composition separated by the percentage of particle size: small (silt and clay), medium (medium and fine sand), and large (gravel and coarse sand) in each quadrat and their respective areas.



Graph 3: Percentage of organic matter from the LOI test separated by area and depth of the soil samples.

3.4 Water Retention & Infiltration

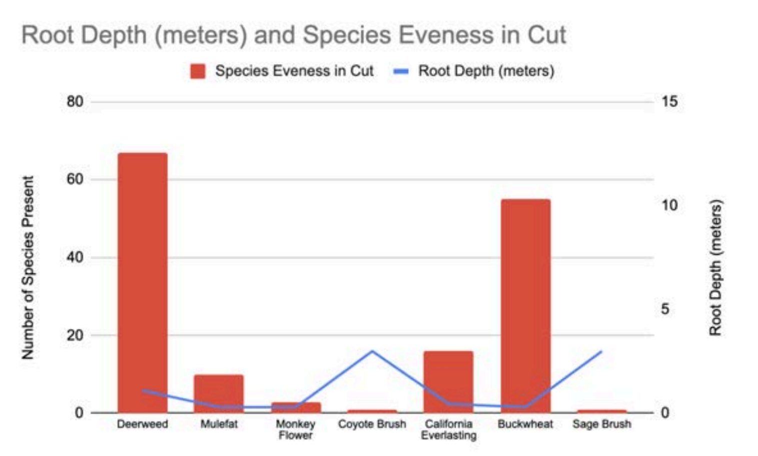
The cut has the highest volume of water retained and the longest water infiltration time. Chaparral has a significant difference in water infiltration time on February 3rd compared to April 2nd.

Area Tested	Water Retention (mL)	Water Infiltration- Feb 3rd (minutes)	Water Infiltration- April 2nd (minutes)
Cut	16.3	3.8	3.4
Ecotone	15.8	1.9	2
Chaparral	12	16	1.9

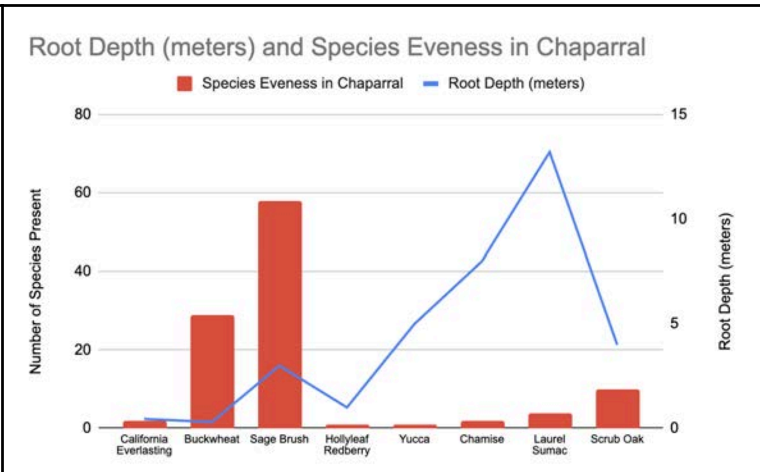
Graph 4: Water retention and two water infiltration tests separated by area.

3.5 Plants and Root Depth

Plants in the cut contain a smaller root depth range from 0.3 to 3 meters compared to the chaparral, which is 0.3 to 13.2 meters. These plant species counts are courtesy of our group partners (Gamboa and Walsh).



Graph 5: Species Evenness and Root Depth in the Cut



Graph 6: Species Evenness and Root Depth in the Chaparral

4.0 Discussion

While nutrient data (Graph 1) suggests that the disturbed soil is consistent with mature chaparral, clay content (Graph 2) and water retention and infiltration (Graph 4) characteristics are inconsistent with the chaparral soils. The clay content in the disturbed area is higher than the chaparral, an indicator of an early successional stage (Lu, Moran, and Mansuel, 2002). High clay content is also consistent with increased water retention and lower infiltration, compared to the mature chaparral.

Looking at the Organic Matter Content (OM) shown in Graph 3, the hypothesis suggests that the cut will have lower OM as it is in an earlier successional stage. This finding is true at the surface, but not the subsurface. Plant species and root depth data (Graphs 5 and 6) help explain this pattern. Plants in the cut have shallow roots ranging from 0.3 to 3 meters, while roots in the chaparral range from 0.3 to 13.2 meters. The cut shows a higher OM% below 10 cm, while the chaparral had a higher surface level OM%. This differs from Schomakers' findings in Taiwan, where OM increased consistently in soils during succession. The excavation in the cut altered the soil structure and subsequent pioneer species plant growth, leading to this unique OM distribution, which is supported by Figure VII's root distribution model. The higher OM below 10 cm is due to the roots decomposing above the parent material, which has not been broken down compared to the mature chaparral. Meanwhile, chaparral's deep roots and dense vegetation above ground result in a higher surface level OM% and lower OM in the 10-25 cm subsurface.

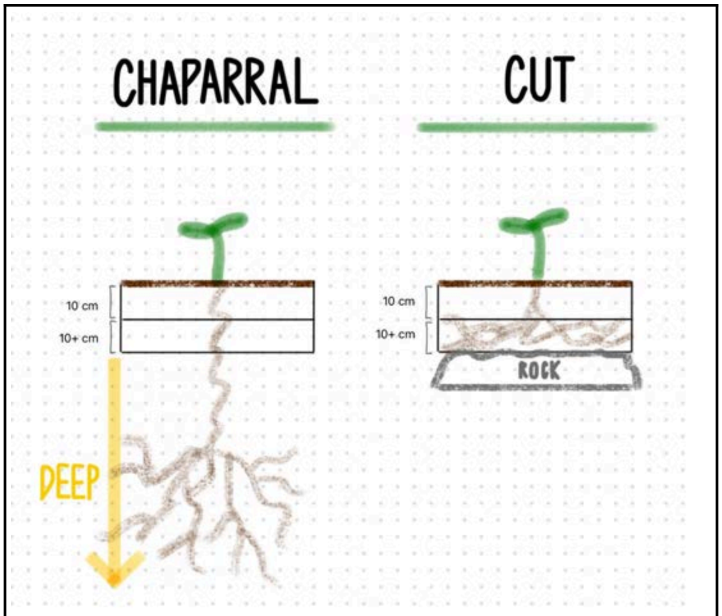


Figure VII: Diagram showing how the excavation influences root depth and organic matter content in the cut compared to mature chaparral

One interesting observation in the data is the water infiltration times for the chaparral on February 3rd compared to April 2nd. Two weeks before the February 3rd date, there were 0.64 centimeters of rainfall, while the week before had no rainfall. Dry conditions leading up to February 3rd contribute to soil water repellency, which contributed to the long water infiltration time of 16 minutes. A faster water infiltration time of 1.9 minutes was achieved on April 2nd due to smaller rain events leading up to the date and higher humidity, which decreased water repellency.

Based on the data, Vogl's expectation that the chaparral will not return after a severe disturbance needs revision. However, he does emphasize the complexity of chaparral ecosystems, which is what this study shows. The results of this study indicate that the cut is primary succession due to the severe disturbance caused by the excavation. Graphs 1, 2, and 4 and Graphs 3, 5, and 6 support primary succession in the disturbed area of the cut and show how disturbance history and ecological context influence soil content. Overall, these findings highlight the importance of understanding how severe disturbances affect long-term ecological processes. This insight offers valuable guidance for future restoration efforts. Further studies should investigate the hydrophobic characteristics of chaparral soils further, specifically whether seasonal changes still affect chaparral soils if they are mixed with other types of vegetation, which would likely change the composition of the soil. Also, looking at hydrophobic characteristics in different levels of succession in chaparral soils could show how this hydrophobic trait develops over time.

5.0 Conclusion

This study confirms that primary succession is occurring in the disturbed chaparral area, the Cut. The comparison of soil properties such as texture, organic matter content, and pH between the Cut, the ecotone, and the surrounding mature chaparral indicates that while soil development is slow, ecological recovery is progressing. These findings support the hypothesis that primary succession can occur in chaparral ecosystems, despite previous expectations that recovery would be minimal following severe disturbance, as suggested by Vogl.

Overall, the results highlight the resilience of chaparral ecosystems and their potential for recovery through natural succession. Further studies should focus on long-term monitoring to observe plant colonization, microbial community shifts, and the trajectory of soil recovery.

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7.0 Appendix

7.1 Nutrient and pH test

https://docs.google.com/document/d/1sDeYxFlWnU7In00F5NLfE3zKYsiF291aVEz1KYjW7hc/edit?usp=sharing

7.2 Water Retention Test

https://docs.google.com/document/d/1PccQgVsjEDHBfvNX4q8TBHWNpZz9HW8mkKvCVLXFFWQ/edit?usp=sharing

7.3 Water Infiltration Test

https://docs.google.com/document/d/17jRvtYOEOGt_6TGZ49h-H9XGh4hSYKa3QiBVY9gM1Y8/edit?usp=sharing

7.4 Sieve Test

https://docs.google.com/document/d/1KnW8LDznYV5tGp-amtoaONPKdJB6_44CF_01kYV5YF4/edit?usp=sharing

7.5 LOI Methodology

https://docs.google.com/document/d/13F9ZxvEAPJp5WGVwMINxwa7xuaN2YpAuS1-RKQVx88Q/edit