READING BETWEEN THE BRANCHES: EXPLORING THE GEOGRAPHY OF TREE MORTALITY IN BLUE OAK WOODLANDS

A THESIS

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ABSTRACT

The history of human activity, the local topography, the Mediterranean climate, and changes in wildfire regime have all had a significant impact on the spatial distribution of oak forests in the Sierra Nevada. This study aims to explain the rate of tree fatalities during drought periods by either ecology (e.g., tree density and thus competition) or geography (e.g., environmental variables such as topography). The purpose of this study is to test the following hypotheses that tree death rates are higher on steeper slopes than gradual slopes, that tree death rates are higher on south and southwest facing slopes as opposed to north and northwest facing slopes, and that tree death rates are higher on slopes with higher tree density because of competition between different tree species. This study used UAV-derived imagery taken between 2018-2022 to identify oaks that died during that period at River Ridge Ranch, CA. A mortality analysis of the eastern half of the ranch found that west facing slopes saw the greatest amount of morality even adjusted for tree density. The results also demonstrate that, as a result of competition between various tree species, tree death rates are higher on slopes with higher tree densities. This lends credence to the hypothesis that tree density eventually influences mortality to a greater extent than topography.

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CHAPTER 1

INTRODUCTION

The spatial distribution of oak woodlands in the Sierra Nevada region in Tulare County, California has been strongly influenced by its Mediterranean climate, local topography, wildfire regime change, and history of human activity. Native Americans regularly burned oak woodlands as part of their management regime resulting in a decline in conifer cover and an increase in oak tree cover (Mensing 2006). More recently, many of these oak woodland regions experienced a dramatic shift in land management practices with the arrival of European settlers in the 16th century. The scientific community is in consensus that the western half of the U.S. is experiencing levels of drought and increased warming (Piechota et al. 2004; Leeper et al. 2022). Evidence suggests that the increased intensity and duration of warm temperature and drought California has experienced from 2010 to 2022 is restructuring the composition of these forested and woodland areas, causing an observable increase in vegetation mortality (Pile et al. 2019; Das et al. 2020; Dwomoh et al. 2021; Huesca et al. 2021).

Much of the academic literature has focused on conifers and other higher elevation species in an effort to understand the extent of which the combination of drought events, fire suppression, and warming temperatures have altered tree cover in the southern Sierra Nevada region. Less attention has been placed on tree deaths in the oak woodlands, which are located at lower elevations. More recently, however, the intense droughts in central California (2012-2016 and 2018-2022), have prompted a few studies of oak tree mortality. A common theory to explain mortality has yet to emerge, however, because, as Das et al. (2020) notes, “the effects of increased drought frequency and severity play out across the range of blue oak woodlands will likely vary by locale” (Das et al. 2020, 172). Much of our understanding of oak mortality is limited due to the complexity of factors and variables that may contribute to oak mortality. Complicating matters is the long and complex history of shifts in oak-woodland land management which have had immense impacts on oak tree establishment. For example, the works of Mensing (1992) and McClaran and Bartolome (1989), demonstrated that the influx of settlers to California during the mid-1800s coincided with a massive blue oak regeneration event followed by a plunge in annual regeneration. Swiecki, Bernhardt, and Drake (1997) determined that the current rate of sapling recruitment was insufficient to recover the loss from mortality. The findings suggested that the regeneration of oak commonly occurs in optimal locations within suboptimal conditions and suboptimal locations within optimal conditions (Swiecki, Bernhardt, and Drake 1997). Specifically, blue oak saplings were more likely to be found in somewhat mesic settings at the most xeric places they evaluated. These included areas with deeper soil, slopes that faced north, and topographic features that tend to gather runoff. However, the site variables were frequently linked to extensive mixed hardwood canopy cover in mesic areas. Blue oak saplings typically appear in the more xeric and open places within mesic environments since they cannot thrive under dense canopy. It should be noted that Swiecki, Bernhardt, and Drake's research focused on sapling survival and regeneration, which is on the opposing side of mortality. This indicates that in order to generate the open canopy conditions for successful recruitment, the current stand of blue oaks would have needed to perish in order to have their acorns sprout and mature. Conditions that are ideal for sapling survival may be tied to the mortality of the parent tree, meaning that the previous blue oak stand generation could be experiencing competition pressures in addition to drought-related ones that lead to increasing mortality.

In a more recent study, Das et al. (2020) surveyed oak mortality in Sequoia National Park and found that substantial canopy cover had died back during the 2012-2016 drought. Das reaffirmed Swiecki's spatial characteristics of mortality, in that the study found a continued decline in blue oaks at xeric locations. Williams et al. (2015) noted that the southern part of the blue oak range experienced the drought most severely, leading Das to suggest that drought-related mortality may also be less intense in more mesic regions. Seemingly contradictory at first glance, the explanation for the decline in blue oaks at xeric locations ties back with the findings of Swiecki–that the drought adaptations of blue oaks cannot address the intensity and duration of lack of water on these dry sites. An alternative hypothesis would be that blue oak deaths may elevate in more mesic locales where tree density is higher resulting in competition from other tree species, such as live oaks or buckeye trees, especially during intense drought events.

Purpose of the Study

The purpose of this study is to determine whether geography (e.g., environmental conditions such as topography and edaphic conditions) or ecology (e.g., tree density and thus competition) explain the rate of tree deaths during drought periods remain unanswered questions. If geography matters most, we would expect to find tree deaths concentrated on south and southwest facing hillsides and on steeper slopes, which theoretically have the most xeric conditions. If tree density (competition) matters most, we would expect to find more tree deaths in areas with more dense tree cover (often on north-facing slopes or in ravines) where blue oaks would be out-competed.

One approach needed to gain a better understanding of the drivers involved is a multi-year vegetation study of tree death across a heterogenous landscape. One challenge, however, is how to best capture high quality, representative data of blue oaks over a period of multiple years.

Most commonly researchers have focused on analysis of either pre-determined plots, the use of low-resolution satellite imagery, or a combination of the two. While these approaches have produced some useful findings, they also highlight that uncertainty revolves around how the combination of topography, ecological competition, and increased drought events influence the pattern of mortality. I contend that a strategy that combines high-resolution photography from unoccupied aerial vehicles (UAVs) with field surveying will be successful in detecting the geography of oak mortality by examining specific dead trees throughout the research site.

The primary objective of this study is to conduct a mortality analysis to measure the level of dieback that has occurred during the 2018-2022 drought to determine the environmental factors that explain or correlate with tree deaths. A secondary objective is to compare the causes of tree death during the 2018-2022 drought with causes of trees that died prior to 2018. The 2018-2022 drought was especially intense in central California and may be representative of future droughts due to climate change (Stewart, Rogers, and Graham 2020).

River Ridge Ranch & Institute (RRR) is an exceptional space to perform this research. It is an example of a landscape that shares many of the same topographic qualities as other working ranches within the Sierra Nevada foothills. Its multiple slopes vary in steepness and face in several directions, allowing for the opportunity to measure mortality and dieback from samples that are highly representative. Understanding the dynamics that occur RRR could be extrapolated to other ranches throughout the Sierra Nevada foothills.

This study builds upon the works of Alexander et al. (2022) who conducted a study on detecting oak mortality through imagery analysis at RRR. Their goal was to map and identify all dead trees to measure the carbon sequestering capacity of the ranch post-grazing. Partial results of Alex et al.'s study will help determine the locales on the ranch in which mortality is most exacerbated.

This study will determine the significance of a variety of different factors thought to be important in affecting tree mortality. Here, mortality rate is defined as percentage of tree deaths (number of deaths/tree density per 50m x 50m plot). Specifically, it will focus on geography (slope and aspect) and tree density (competition). North-facing slopes tend to be much cooler, and wetter compared to their southern-facing counterparts in the Northern hemisphere; this phenomenon is well known in biogeographic literature. In addition, steeper slopes tend to have shallower, less developed soils with less water storing capacity (Guerrero, Hinojosa-Corona, and Kretzschmar 2016). The hypotheses for this study are as follows:

1. Tree death rates are higher on *south and southwest facing slopes* as opposed to north and northwest facing slopes, adjusted for tree density and steepness.
2. Tree death rates are higher on *steeper slopes* (> = 45 degrees) as opposed to more gradual ones (flat 0-4.9 degrees, gentle 5-9.9 degrees, and moderate 10-19.99 degrees) adjusted for tree density and terrain steepness.
3. Tree death rates are higher on *slopes with higher tree density* due to competition between different trees and tree species.
4. Patterns (causes) of tree death do not vary between study periods (i.e., the 2018-2022 drought did not cause a unique pattern of tree death).

The expectation of this research is that N and NW-facing slopes and locales where the density of oaks is high will have higher mortality rates relative to S and SW-facing slopes, steep slopes, and locales where density is lower. Oak woodlands play a critical role in holding the foothill soils in place and are responsible for governing the quality of water and its flow in watersheds, rivers, and streams. They hold the highest amount of terrestrial biodiversity than anywhere else in California (Reiner and Craig 2011; Stahle et al. 2013). The significance of this research lies in its potential to enhance our understanding of the complex interplay between environmental factors, such as geography and tree density, in influencing tree mortality during drought periods. By investigating these factors over a multiyear period using high-resolution aerial photography and field surveying, this study not only contributes valuable insights into oak mortality patterns but also provides critical information for the conservation and management of oak woodlands, which are essential for biodiversity, soil stability, and water quality in California's ecosystems.

CHAPTER 2

CONCEPTUAL FRAMEWORK

To determine the geography of tree death, we need to separate the effects of topography from the effects of ecology, which in this case is tree density. Issues concerning California's oak populations on recruitment, regeneration and the drivers affecting their ability to self-sustain (and thus, mortality) have been heatedly debated in the literature since the 1980s. It has been well established that the Southwestern U.S. is experiencing increasing levels of drought and warmer temperatures, and that the vegetation profile of Blue Oak Woodlands (BOW) of California are responding. Landowners and foresters are now concerned with the increase in recent mortality events within this endemic woodland type. Studies that investigated the historical ecology of BOW explored the shift from Indigenous land management to European practices, including its impact on blue oak distribution. Other studies conducted aim to explain what mediates tree mortality during drought in the Sierra Nevada. Within the southern portion of the Sierra Nevada, blue oaks have adapted to become a drought-tolerant species. Additionally, the primary concern of studies that examined the dynamics occurring in BOW were centered around oak recruitment and regeneration, and not mortality itself.

2.1 Historical Ecology of Blue Oak Woodland-Pre- & Post-Settlement

California's oak woodlands have undergone centuries of land use change and several other modes of disturbances. There is a consensus in the literature that European settlement has contributed to oak woodland disturbance and the mortality events that followed. These disturbances associated with European settlement include the introduction of livestock grazing, fire suppression, the ending of indigenous land management practices, and urban development (e.g., wildlife fragmentation). The major theory regarding the current distribution of oak woodlands and the historical events that led up to it was put forth by Mensing and Swiecki in the early 1990s. In 1992, Mensing's conclusions, complemented by Vankat and Major's work (1978), indicated that the present stand structure and density of oak woodlands differ from those observed in the pre-European period. Further results in tree dendrochronology and ancient pollen studies, along with analysis of native land use management led Mensing to propose a paleo historical account of California's oaks (Mensing 2015). The maximum spatial distribution of oak woodlands in California are proportional to that of the conifer's distribution; their range tended to increase during the warm, interglacial periods, while the maximum conifer distribution dominated during glacial maximums (Mensing 2005).

The oak pollen percentage saw a 40 percent increase following the arrival of Europeans and Americans after 1860, implying a potential expansion in the range or increased density of oak woodlands during the American period. The uptick in oak pollen also coincides with the gold rush era that occurred in California during that same timeframe (Mensing 2006). Although these records were for the Santa Barbara coast, the dynamics that occurred there could very well be indicative of many other oak woodland regions across the state where European settlement occurred. The European perspective on fire differed from that of the native Californians, as they needed unburned pasture for grazing livestock (Mensing 2006). These fire suppression efforts may have led to an increase in recruitment of oaks during that period, perhaps explaining the age structure and stand density of the BOW that we observe today (Mensing 1992). The issue of blue oak regeneration was continued by Swiecki in the following year; his findings were in line with that of Mensing's, in which the study concluded that "much of the historical flush of blue oak regeneration that coincided with settlement in the late 1800s and early 1900s was due to the release of existing advance seedling regeneration due to widespread tree cutting, at a time when browsing pressure was not excessive" (Swiecki, Bernhardt, and Drake 1993, 104).

2.2 Oak Woodlands & Drought

The academic literature on blue oaks up until the 2010s has primarily been focused on patterns of recruitment, regeneration, and seedling survival, and much less so on the relationship between site conditions, drought, and mortality. However, blue oak surveys conducted in 1998 had led to the hypothesis that blue oak saplings "tend to occur in the worst sites in the best locations and the best sites in the worst locations," suggesting that mortality is occurring most at locales in which water availability is low such as south-facing slopes or areas where soil depth is shallow. Given that blue oaks have difficulty competing under dense canopy and have adapted to become drought tolerant, blue oak mortality is expected to occur where competition for available water is high (Swiecki and Bernhardt 1998).

Findings from laboratory studies conducted by Gorden, Menke, and Rice (1989) and Gordon, Rice, and Welker (1991) indicated that increased competition for soil moisture had a significant impact on blue oak mortality, which was further supported by field experiments highlighting the crucial role of water availability in oak seedling survival. The recent drought periods California has faced from the early 2000s has led to more focus in understanding the implications of warming temperatures and low water availability in the southern region of the Sierra Nevada. Even though advancements in mortality dynamics have been made, the determinants of when and where these events occur in a given landscape are still poorly understood (Dorman et al. 2015). In regard to drought, much of the early research on BOW largely left this aspect unexplored since other dynamics such as fire, grazing, clear-cutting, etc. were more substantial at the time (Allen-Diaz et al. 1992; Swiecki, Bernhardt, and Drake 1993;

Mensing 1992, 2005, 2006, 2015). The association between mortality events and the second-order casting effects from drought due to warmer temperatures and decreasing water availability has been noted by various researchers (Williams et al. 2015; Young et al. 2017; Paz-Kagan et al. 2017; Das et al. 2020; Huesca et al. 2021). What studies regarding broader ecosystem dynamics have lacked is a clear definition of what they define as "drought." A literature review conducted in 2019 revealed that many ecologists have a plethora of ways in characterizing drought (e.g., low soil moisture, reduced streamflow, etc.), but very few actually define drought conditions within the context of their research. Surprisingly, 30 percent of the publications simply associated "dry conditions" with "drought," giving no information about the drought circumstances (Slette et al. 2019).

Numerous studies have explored the implications of drought in both Sierra Nevada woodlands and forests (Paz-Kagan et al. 2017; Das et al. 2020; Huesca et al. 2021), while only a few have mentioned the specific characteristics that give their definition of drought contextual background (Fettig et al. 2019; Dong et al. 2019). This is critical to note because regions across California experience drought in various ways. Over the past few decades, a changing climate with a wetter-warmer Northern California and a drier-hotter Southern California has been noticed and is likely that this trend will continue in the 21st century (Dong et al. 2019).

From 2012 to 2016, California experienced one of the most severe droughts in more than a century (Williams et al. 2015; Huesca et al. 2021). The risk of increased drought events is especially concerning for woodland mortality as the Central and Southern Sierra Nevada are already semiarid, creating conditions that are at or near tipping points for changes in ecosystem composition and function (van Mantgem et al. 2009; Allen et al. 2010; Weed, Ayres, and Hicke 2013; Trenberth et al. 2014). For the context of this study, drought will be classified as both meteorological and hydrologic. A drought may be classified as a hydrological drought if it affects river and stream flow and a meteorological drought is what occurs when there is a period of low precipitation, which is how most droughts start. If low precipitation is persistent enough, it can lead to low moisture in soils, leading to an agriculture drought. This can also affect BOW as the majority of these woodlands are within privately held ranches and need sufficient water supply to support livestock and grazing. Contrary to most land at higher elevations, which is owned by the government and is considered public land, 80 percent of California's oak forests and woodlands are privately owned.

2.3 Oak Woodlands and Working Landscapes

Most of this private land is utilized for grazing, particularly for beef cattle. The San Joaquin region's oak forests are privately held in 73 percent of cases. By 2040, development might threaten about 250,000 acres of oak woodlands in the San Joaquin Valley (Gaman and Firman 2006). Huntsinger and Fortmann's (1990) study of oak woodland managers and landowners discovered that 75 percent of California oak woodlands are grazed by livestock. Approximately 23 million hectares within the state of California are classified as rangeland (Huntsinger and Bartolome 2014). It is important to note that environmental variables, as well as political and social influences, play a significant role in the location and spatial distribution of oaks within ranchlands and working landscapes.

Working lands are considered to consist of mostly ranching rangelands, farms, and forests. Given the current problem of adapting to more extreme climatic conditions, all while preventing further loss of woodland biodiversity, the significance of combining conservation value with production value in such geographic areas is a relatively new challenge posed to the conservation world (Kremen and Merenlender 2018; MacIntosh 2019). By addressing the behavioral and evolutionary ecological mechanisms that permit other species to coexist in human landscapes, as well as strategies to encourage cohabitation, the idea of ecological reconciliation seeks to reconcile biodiversity conservation with human growth. Adopting such frameworks can help land managers by giving them the philosophical underpinnings they need to maintain the working lands' production value and conservation value without having to make any compromises.

These determinants serve to dictate the existing vegetation structure we see within the southern portion of the Sierra Nevada. With the increasing encroachment of human development, importance has been placed on preserving the environmental integrity of undeveloped lands as open space for providing education and research opportunities as well as recreational activities. One such example of the local and regional efforts to maintain the environmental quality of these landscapes is seen through the advocacy and implementation of conservation easements (Huntsinger and Fortmann 1990; Huntsinger and Bartolome 2014; Rissman et al. 2006; Santos and Thorne 2010). An easement is essentially a contract that forbids certain sorts of land development and places limits on property owners. A landowner has several options in which to place an easement on their land, either through donation or purchase, and a land trust would prohibit any activities that are deemed unfavorable to the property's natural values, which includes restricting the right to subdivide the land, add any human development, sell the land's water, among other limitations (Reiner and Craig 2011).

The adoption of conservation easements has increased by 34% in California since 2005 (Huntsinger and Bartolome 2014). It should be noted however, that conservation easements can allow commercial grazing to continue on the land depending on the agreement. This is crucial to mention as private landowners of working landscapes (e.g., cattle ranches) hold some of the

Western US' "best remaining" natural regions and using these easement acquisitions have become land trusts' primary activity (Merenlender et al. 2004). It is important to note that most of the lack of regeneration studies focused on these working landscapes (Huntsinger and Fortmann 1990; Mensing 1991; Swiecki and Bernhardt 1998; Gaman et al. 2006; Huntsinger 2014; White 2015). Working lands with lengthy use histories present intriguing research questions when easements are set up for long-term study and landscape preservation while allowing for continuous production value of the land (MacIntosh 2019).

The prioritization of oak woodlands through this framework and its influence in shaping future land use and regional planning reflects the social and cultural values towards preservation and restoration of these areas.

2.4 Mapping Efforts in Blue Oak Woodlands

There are several methods that have become favored in monitoring the health and status of California's blue oaks. These methods include the use of monitoring individual trees in predetermined plots (Swiecki, Bernhardt, and Drake 1993; Fettig et al. 2018; Pile et al. 2019; Das et al. 2020) and other forms of data such as annual land-cover and land-surface change products from the U.S. Geological Survey (Dwomoh et al. 2021). Yet, mapping the extent of mortality in blue oak regions has been fraught with obstacles in accurately depicting dieback. Tree plots have been proven to be an adequate way for long term monitoring, but this generally requires a dedicated team and sophisticated logistics in executing that may not be available to some research capacities.

Previous literature has not addressed the considerable difficulties that multiscale techniques face when attempting to remotely sense tree mortality in open-canopy woodland ecosystems. A prime example is due to the size of the image pixel and how open these woodland canopies can be, tree mortality spectral signatures can get diluted (Smith et al. 2019). In her study, Huesca et al. (2021) observed that the 18m x 18m pixel size posed challenges in distinguishing whether detected mortality consisted of multiple dead trees within a pixel or a single dead crown. Enhanced spatial resolution data might have aided in resolving these distinctions. Meter-level image resolution is adequate to monitor mortality in closed-canopy forests, but not for open-canopy regions.

Determining the mortality of individual trees is not possible even at 1 meter resolution, and it has been demonstrated that UAV photogrammetry yields better results for landscape analysis compared to satellite data, whose resolution tends to be in the meter scale. This has led some studies to call for a new approach in either fusing high and moderate spatial resolution, adopting UAVs, or using regression models to detect and map tree mortality in sparse, open canopy woodlands (Paz-Kagan et al. 2017; Campbell et al. 2020; Iizuka et al. 2018). Land managers are showing a great deal of interest in UAVs' ability to map minute changes in vegetation cover at different spatial and temporal scales using layered high-resolution data. Although UAV use come with their own sets of challenges, the literature is in consensus that land management decisions have benefitted from products generated using autonomous or semi-autonomous UAV equipment (Zaman, Jensen, and McKee 2011; Du et al. 2017). For rangeland management, UAVs can produce very high-resolution imagery to help monitor vegetation change and health over time and evaluate the efficacy of previously applied management programs (Rango et al. 2006).

2.5 Summary

Building upon the works of historical ecology and tree establishment from both Mensing and Swiecki, the goal of this study is to uncover whether history explains mortality more adequately than geography. Seeking ways to better understand whether ecological competition (e.g., tree density) between trees or site-specific topography plays more of an influence on oak mortality in the southern Sierra Nevada is of great relevance. Historical ecology is less important if topography is the primary cause of tree demise. In other words, it would not matter much how trees were first established, but if tree density is important, history matters more than geography. If tree density (competition) is the most important factor, we would anticipate that there would be more tree deaths in regions with more dense tree cover (typically on north-facing slopes or in ravines), where blue oaks would be outcompeted by the other major species—live oaks and buckeye trees. However, if geography is the most important factor, findings would suggest that south and western facing slopes and areas of high stand density are expected to have more mortality in comparison to their northern facing, less dense stand counterparts. Using fieldwork based oak data, along with slope and aspect products derived from UAV imagery at the research site of RRR, the spatial distribution of mortality will be assessed. This allows for the unique opportunity to conduct a geospatial analysis experiment to determine if mortality can be attributed to recent drought conditions the region has faced since the mid-2010s.

2.6 Descriptive Background of the Study Area

Chapter 3 consists of a more detailed description of this research's study area; this section provides an environmental profile of oak woodlands. The state has a diverse ecosystem due to the near proximity of its five main climatic types. The oak woodland of California is a type of vegetation community that is known as a Mediterranean climate zone (30 to 50 degrees N Latitude). Although dominated by chaparral and coastal scrub communities, this region also supports oak governed savannahs, woodlands, and forests (George 2014).

This zone is characterized by dry, hot summers and cool, wet winters, making it one of the rarer climate types; only five places on Earth have this sort of climate outside of the Mediterranean Sea. Eight different species of California oaks, along with scattered conifers and chaparral make the overstory species composition of these lands. Falling into either one of four categories-forestry, agricultural, rangeland, or natural areas-the primary oak species that are most prominent are Blue Oak (*Quercus douglasii*), Valley Oak (*Quercus lobata*), Canyon Live Oak (*Quercus chrysolepis*), and California Black Oak (*Quercus kelloggii*) (Santos and Thorne 2010). Huntsinger and Fortmann (1990) noted the grassland species that comprise the understory of oak woodlands such as cheatgrass (*Brommus spp.*), Oats (*Avena spp.*), Hordeum (*Hordeum spp.*), Festuca (*Festuca spp.*), Vulpia (*Vulpia spp.*), Medick (*Medicago spp.*), Clovers (*Trifolium spp.*), among others. As noted previously, the species composition of these oak woodlands has changed intensely over the past couple centuries following the arrival of new settlement from Europeans and the subsequent change in land use management thereafter.

CHAPTER 3

METHODOLOGY

3.1 Objectives

The goal of this study seeks to identify the geography of tree mortality at RRR. Specifically, the aim was to determine how canopy density and topography (e.g., slope and aspect) affect the distribution of mortality during an intense multi-year drought. The first objective is to map tree death that occurred on RRR from 2018-present. The following methods were applied to address this objective:

1. Identify live oaks from the summer 2018 UAV flight imagery.
2. Determine which of these oaks died during the study period using the summer 2022 UAV flight imagery.

The second objective is to determine whether slope and aspect or tree density (or some combination) is the most determinant of tree mortality rates. The following methods were applied to address this objective:

1. Generate a mortality map of trees at RRR that died between 2018-2022.
2. Conduct an accuracy assessment from field data to improve the mortality map product.
3. Generate UAV-derived slope & aspect maps.
4. Conduct density analysis on the oak mortality map.
5. Conduct a GIS analysis to determine the relationships between slope ranges, aspect ranges and tree death rates.

3.2 Study Area

The location for this study is RRR situated in Springville, CA, owned and operated by Dr. Gary Adest. Figure 1 highlights the terrain of RRR which contains a riparian corridor to the west, steep woodland hills to the east, and a relatively flat grassy pasture between them. Livestock grazing has taken place on RRR for over a century however, it was most intensive within the flat pasture area. RRR is 722 acres and is in a region that is recognized as a Mediterranean climate zone. This zone spans both the coastal and valley sides of the foothills, from sea level to elevations that reach approximately 6,000 feet (Huntsinger and Fortmann 1990). The weather conditions for this climate are associated with warm, dry summers that average 22 degrees Celsius or greater, and cool, wet winters, when the majority of the annual precipitation occurs. The winter season typically receives approximately 275-900 millimeters of annual precipitation (Santos and Thorne 2010; Huntsinger and Bartolome 2014).

One notable tree species found in the region is the blue oak (Quercus douglasii). Blue oaks are well-adapted to the Mediterranean climate zone and thrive in the area's warm, dry summers and cool, wet winters. Other significant tree species include interior live oak (Quercus wislizeni) and California Buckeye (Aesculus californica) along the hillside, and Cottonwood (Populus deltoides) along the riparian area. The chaparral found in the higher elevations include species such as chamise (Adenostoma fasciculatum), manzanita (Arctostaphylos spp.), and ceanothus (Ceanothus spp.). RRR provides a unique opportunity for a long multi-year study. The history of land management is well documented, as a conservation easement was placed on the property in 2017, which has allowed the ranch to become passively restored. Commercial grazing cattle have been removed from the ranch for at least 5 years, and historical imagery of the landscape exists from 2018. The data used in this research consisted of several different types of datasets. These include aerial imagery generated from two UAV flights, field data on oak health and map products from other studies, and digital elevation models produced from UAV-derived data using photogrammetric processing. Sections 3.3.1 to 3.3.3 describe the data collection and datasets derived for use in this research.

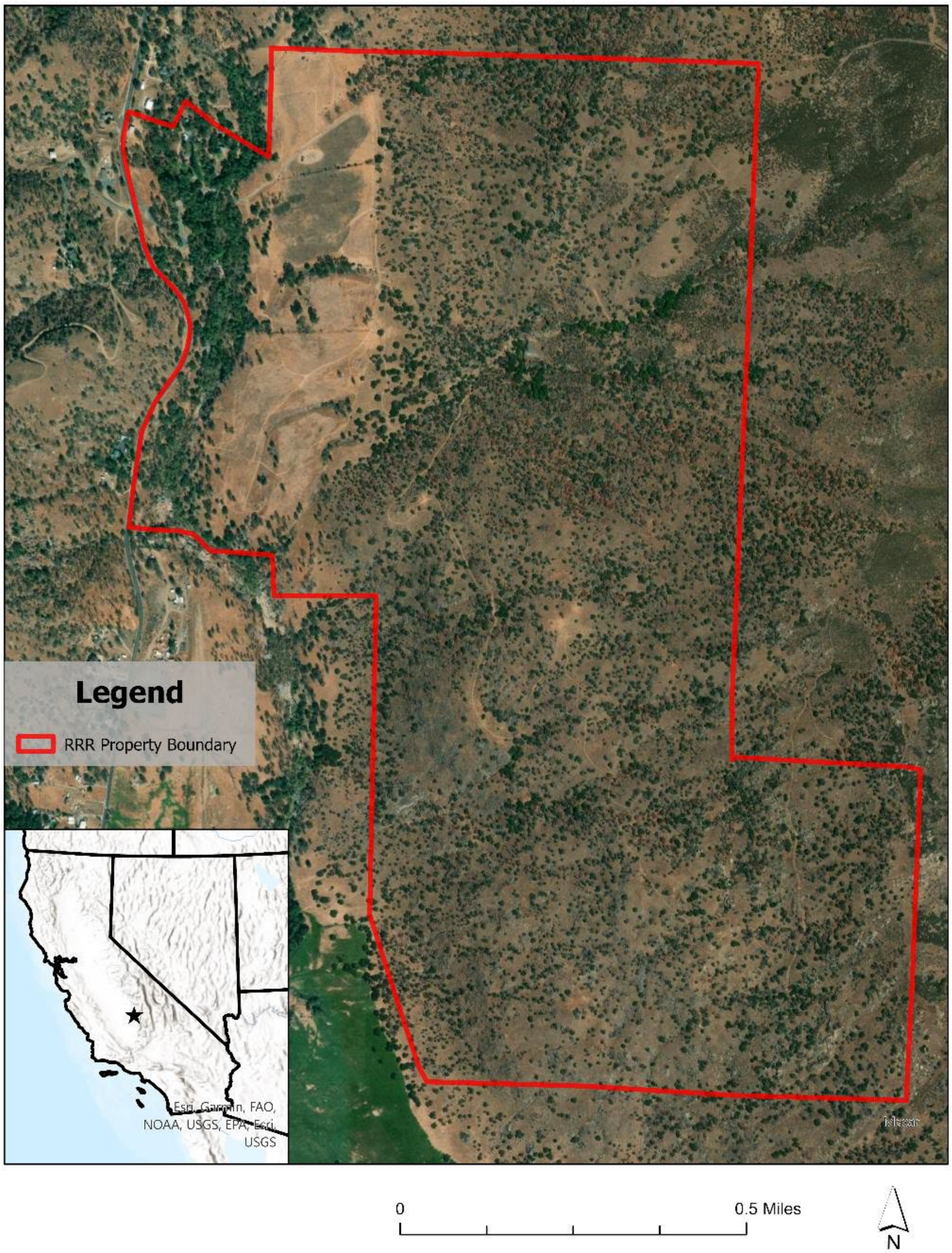

FIGURE 1. Study area of River Ridge Ranch in Tulare County, CA.

3.3 Data

3.3.1 UAV-Derived Data Collection

The UV platform used for data collection was a senseFly eBee fixed wing. The eBee UAV has an operating range of three kilometers and can stay airborne for almost an hour given suitable flight conditions. This unit's autonomous flight and RTK/PPK enabled GPS pairing ability are well-suited for mapping the 700+ acre ranch. Operating a fixed-wing platform in areas where wind patterns are prone to quickly change and third-party interferences are present (e.g., other low-flying aircraft) requires the drone crew to economize battery life (MacIntosh 2019). Outputs can be RTK/PPK supported in either JPEG or DNG and JPEG file formats. The UAV-derived map products used for analysis in this study were based on UAV flights conducted in May 2018 and June 2022. The UAV data acquisition, georeferencing, image mosaicking, and data processing were conducted by Scott Winslow, GIS Lab Manager at the California State University, Long Beach Geography Department Geospatial Research Lab.

Flight plans for the data collection were developed using SenseFly's eMotion3 autonomous flight planning software. The software takes advantage of the eBee's onboard GPS and inertial measurement unit (IMU) to continuously analyze the generated in-flight data (MacIntosh 2019). The UAV flight plans were based on the OEM's recommendations, and each flight used the same pre-mapped plan to reduce inconsistencies from horizontal coverage in Figure 2.

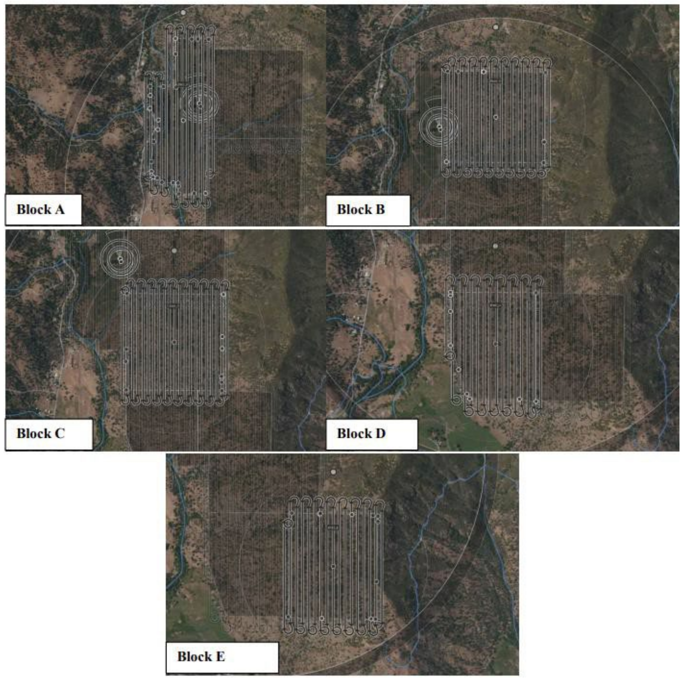

FIGURE 2. Flight lines by block at River Ridge Ranch, CA (MacIntosh 2019).

Flights that were conducted in both May 2018 and July 2022 were flown at a height of 400 feet (122m) above ground level. The eMotion3 flight plan was configured with a 75 percent longitudinal (along-track) and 65 percent lateral (cross-track) overlap between adjacent images. The large acreage of RRR requires multiple flights to map the entire property, so flight blocks (Figure 2) were constructed to make operations more manageable. For safety and legal reasons, Visual Line of Sight (VLOS) is required by the FAA when operating UAV flights. The base of operations was established within RRR's flat pastureland, as it allowed the flight crews to maintain VLOS in flight blocks A, B, and C, along with being a suitable spot for a UAV takeoff and landing site. The terrain within flight blocks D and E is more varied, so a crew of 2-3 CSULB researchers acted as spotters during the UAV flight to maintain VLOS in both blocks. Figures 2 and 3 highlight the flight paths the UAV took within each respective block. Pix4DMapper is a Structure-from-Motion software (SfM) that was used to mosaic the UAV-captured imagery of the entire study area. This SfM software utilizes the series of overlapping images provided by the UAV to create a three-dimensional representation of the landscape by employing stereoscopic photogrammetry techniques (Westoby et al. 2012).

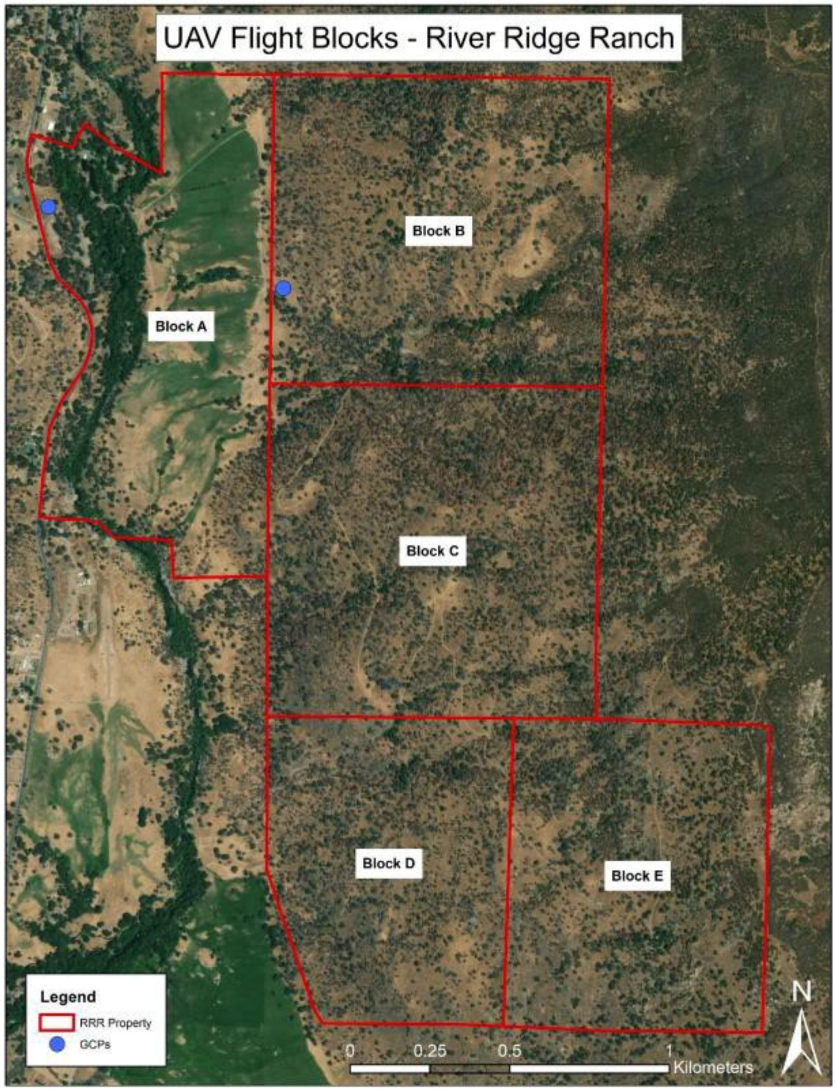

FIGURE 3. The five flight blocks at River Ridge Ranch, CA (MacIntosh 2019).

The products generated from this process, along with mosaiced imagery, are Digital Surface Models (DSM) and Digital Terrain Models (DSM). The mosaicking process involves three steps, which includes: 1) Initial Processing, 2) Point Cloud and Mesh Development, and 3) DSM, Ortho mosaics and Indexing. Step 1 was executed separately for each block due to the large file sizes of the five flight blocks, and this merging process was not undertaken in this study. Duncan Macintosh (2019) integrated all flight blocks into a single project in Pix4DMapper. For details on the specific steps and settings employed in Pix4DMapper, please refer to Table 1.

TABLE 1. Pix4D Processing Settings (MacIntosh 2019)

Step 1 Processing Settings	
Image Coordinate System	WGS 84
Output Coordinate System	WGS 84 / UTM Zone 11N
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image pairs	Aerial Grid or Corridor
Step 2 Processing Settings	
Image Scale	Multiscale, 1 (Original size, Slow)
Point Density	Optimal
3D Textured Mesh Generation	Yes
3D Textured Mesh Settings	Resolution: Medium (default)
Step 3 Processing Settings	
DSM and Orthomosaic Resolution	1x GSD (3.7 cm/pixel)
DSM Filters	Noise Filtering: yes; Surface Smoothing: yes; Type: Sharp
Raster DSM	Method: Triangulation
DTM Resolution	5x GSD (3.7 cm/pixel)

3.3.2 Field Data Collection

Field data were collected by CSULB graduate students in June and July of 2022 to provide ground truth samples for dead trees (Alexander et al. 2022). They classified oaks as either dead or alive based on tree canopy health, as seen in Figure 4. This work was to ultimately prep for the production of an accurate 2022 dead tree map of RRR (Figure 4). The oak mortality map was generated using field data collected in June and July of 2022 to identify dead tree locations. These locations were used as a training model for a Random Forest (RF) algorithm (Alexander et al. 2022). An accuracy assessment was performed to quantify commission and omission errors. Errors of commission indicate sites were misclassified as a dead tree (e.g., highway road, rock outcrops, bare soil), while errors of omission refer to dead trees that were not included (or omitted) from the algorithm's final output. CSULB undergraduates used a random grid approach was used to assess accuracy. A 200m grid line was generated and placed above the RRR AOI creating 60 boxes for accuracy assessment by using the "fishnet" geoprocessing tool in ArcGIS Pro. Each grid box was numbered, and an online random number generator was used to produce approximately 7 boxes from the given range. This allowed for the accuracy assessment to have a 20% representative sample of the AOI.

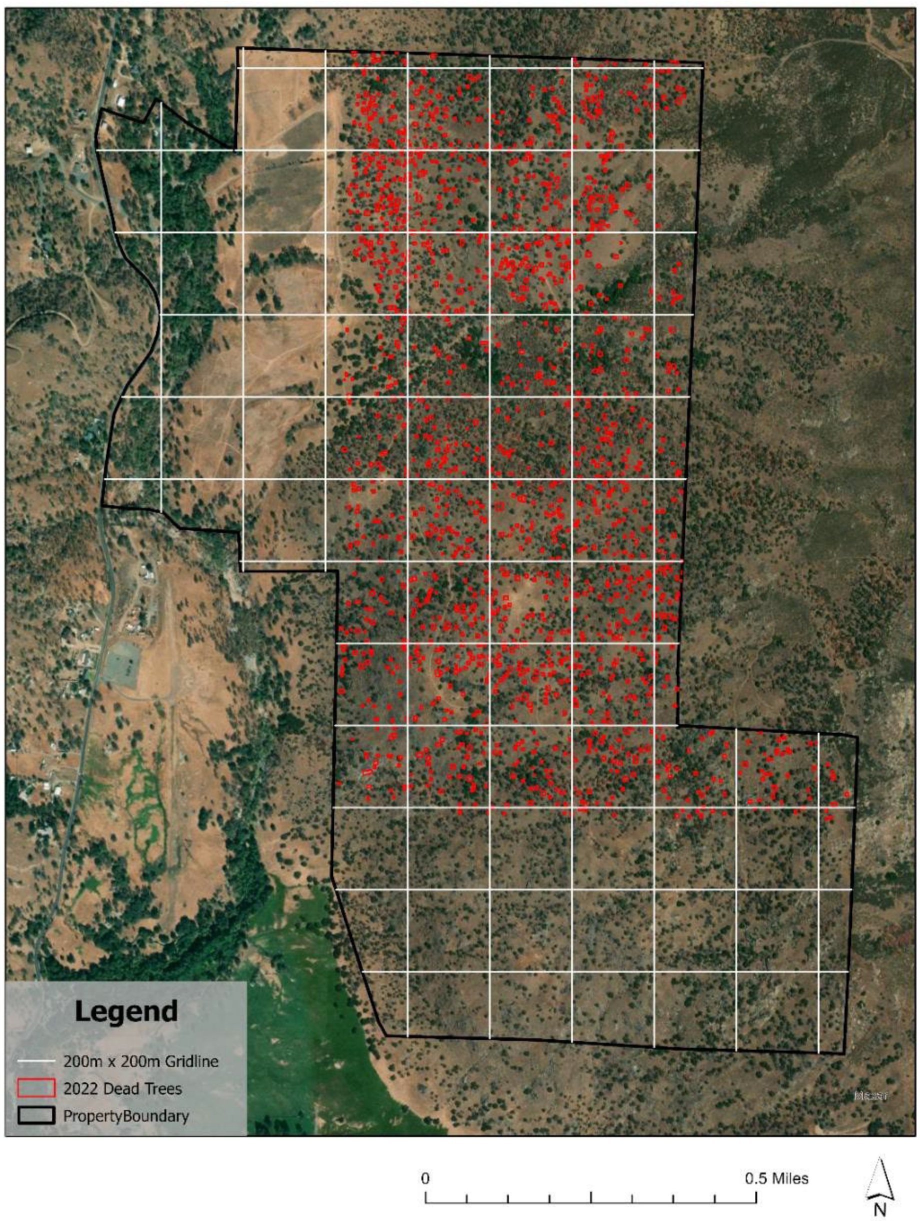

FIGURE 4. Map of accuracy assessment for River Ridge Ranch, CA.

3.3.3 Mortality Analysis

The datasets utilized to create the Slope and Aspect map products were the Slope Digital Elevation Models (DEM) and the Aspect DTM. The Transverse Mercator projection, WGS 1984 datum, WGS 1984 UTM coordinate system, 23,223 columns, and 31,075 rows were the same for each. A slope map was generated from the UAV-derived Digital Terrain Model (DTM) by employing the Slope tool within ArcPro version 3.0.1, where the output measurement was in degrees, and the method employed was planar. The map was projected using the WGS 1984 UTM coordinate system (Figure 5). To define meaningful slope classification ranges, the symbology histogram based on natural breaks was utilized. Consequently, the eleven default class ranges provided by the Slope tool output were condensed to a total of four categories. Statistical analysis of the Slope output yielded the following values: the minimum slope angle was 0 degrees, the maximum was 89.81 degrees, the mean slope angle was 24.3 degrees, and the standard deviation was 8.21 degrees, indicating a natural bell-shaped curve with no skew. Subsequently, these classes were adapted to better represent the topographical features of the study area. The revised slope categories were designated as follows: Flat (0-4.9 degrees), Gentle (5-10 degrees), Moderate (11-20 degrees), Steep (20-44 degrees), and Severe (> 45+ degrees). The slope map raster was then converted into a vector so that each slope class would be a polygon by employing the Raster to Polygon tool within ArcPro for further analysis.

Aspect represents the direction of a slope. An aspect map was generated from the UAV-derived Digital Terrain Model (DTM) by employing the Aspect tool within ArcPro version 3.0.1, where the method employed was planar. The map was projected using the WGS 1984 UTM coordinate system (Figure 6). To define meaningful aspect classification ranges, the Reclassify tool was employed to modify the values of the aspect raster. Consequently, the ten default class ranges provided by the Slope tool output were condensed to a total of five categories. Subsequently, these classes were adapted to better represent the topographical features of the study area. The symbology of the aspect raster was used to remodify the classes to Flat (-1), North (0-67.49 & 292.5-360), South (112.5-247.49), West (247.5-292.49), and East (67.5-112.49) in Figures 5 and 6, respectively. The raster was then converted into a vector so that each aspect class would be a polygon by employing the Raster to Polygon tool within ArcPro for further analysis in the study as well.

Objective 1 was to identify individual trees that died on RRR between 2018-2022. The first step was to map and remove all trees that were dead prior to 2018 from the mortality map. A normalized difference vegetation index (NDVI) map was created using the 2018 UAV-derived RRR imagery. The NDVI spectral signatures of live and dead vegetation differ greatly, so vegetation was considered dead if its spectral signature was -0.03 or below, compared to live and healthy vegetation of 0.52 or above. These values were generated by taking the NDVI values of both 30 healthy and dead trees from the AOI and calculating the values to get the average NDVI (spectral values) for both. The spectral values of vegetation the fell between the alive and dead values indicate those trees were experiencing stress (Ambelu 2019). If a tree's spectral signature was -0.03 or lower as opposed to 0.52 for living and healthy vegetation, the trees were pronounced dead. The 2018 RRR dead tree map was generated by highlighting only dead or extremely stressed vegetation from the 2018 NDVI results. The 2022 RRR dead tree map was generated from the oak mortality data that was collected from surveying in March and June of 2022. The result are 2 maps of RRR–trees that died prior to the drone flight in 2018 and trees that died between 2018 and 2022. Figure 7 and 8 highlights NDVI values for tree canopy health in 2018 and 2022, respectively.

Objective 2 is concerned with determining the locations on RRR where tree dieback is the greatest, and whether stand density is correlated to mortality. The first step was to create a tree density profile of RRR. To do this, a gridline was produced separating the study area into how many? 50m x 50m blocks.

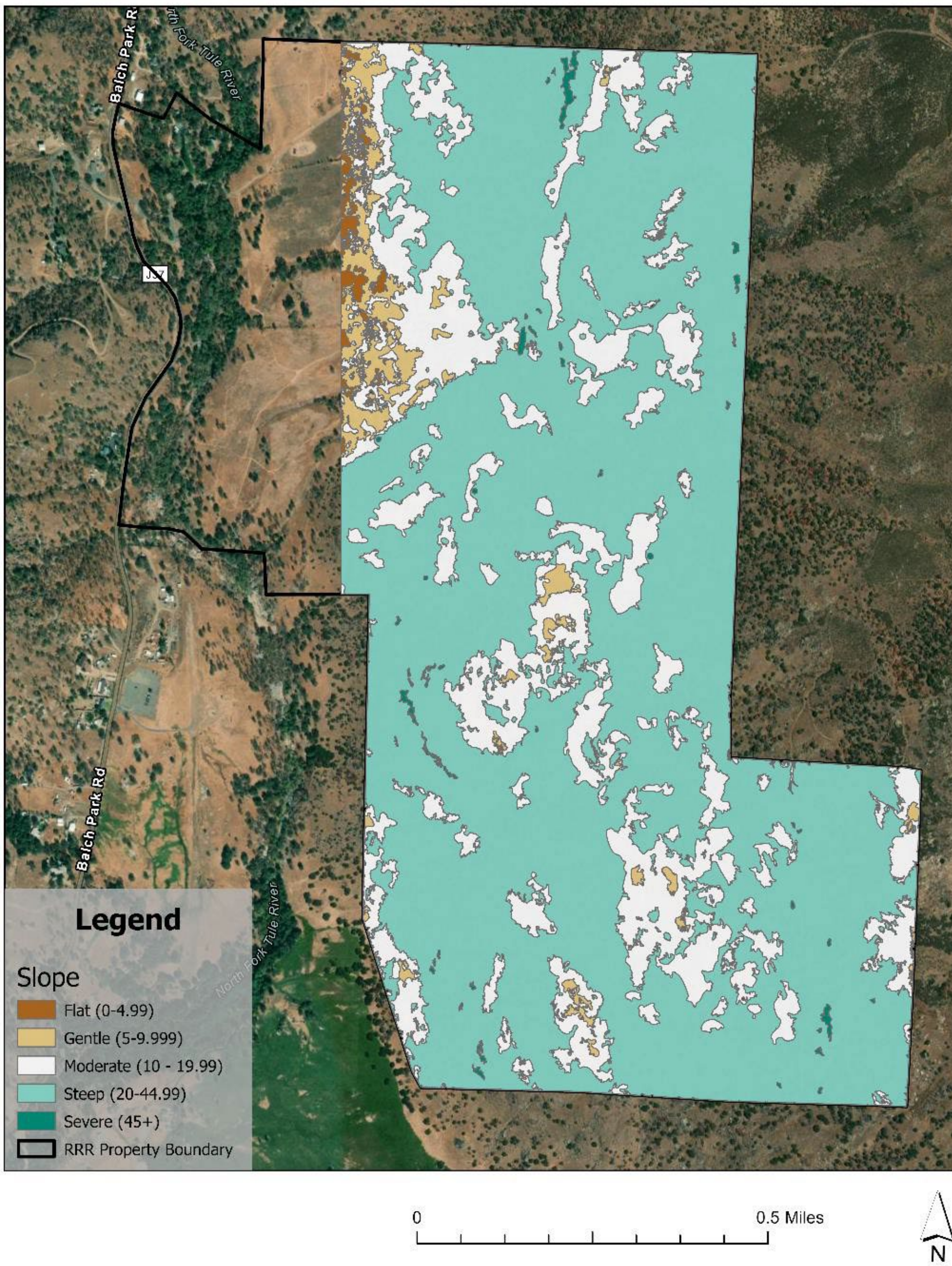

FIGURE 5. Slope map of River Ridge Ranch, CA.

A tree density map was created by overlaying this grid onto a tree canopy map produced by Kenya Creer (Figure 7). The second step was to highlight tree death. A 2022 RRR NDVI image was produced to calculate the density of vegetation on the 2022 RRR imagery to compare any overlap between the imagery and the tree density map.

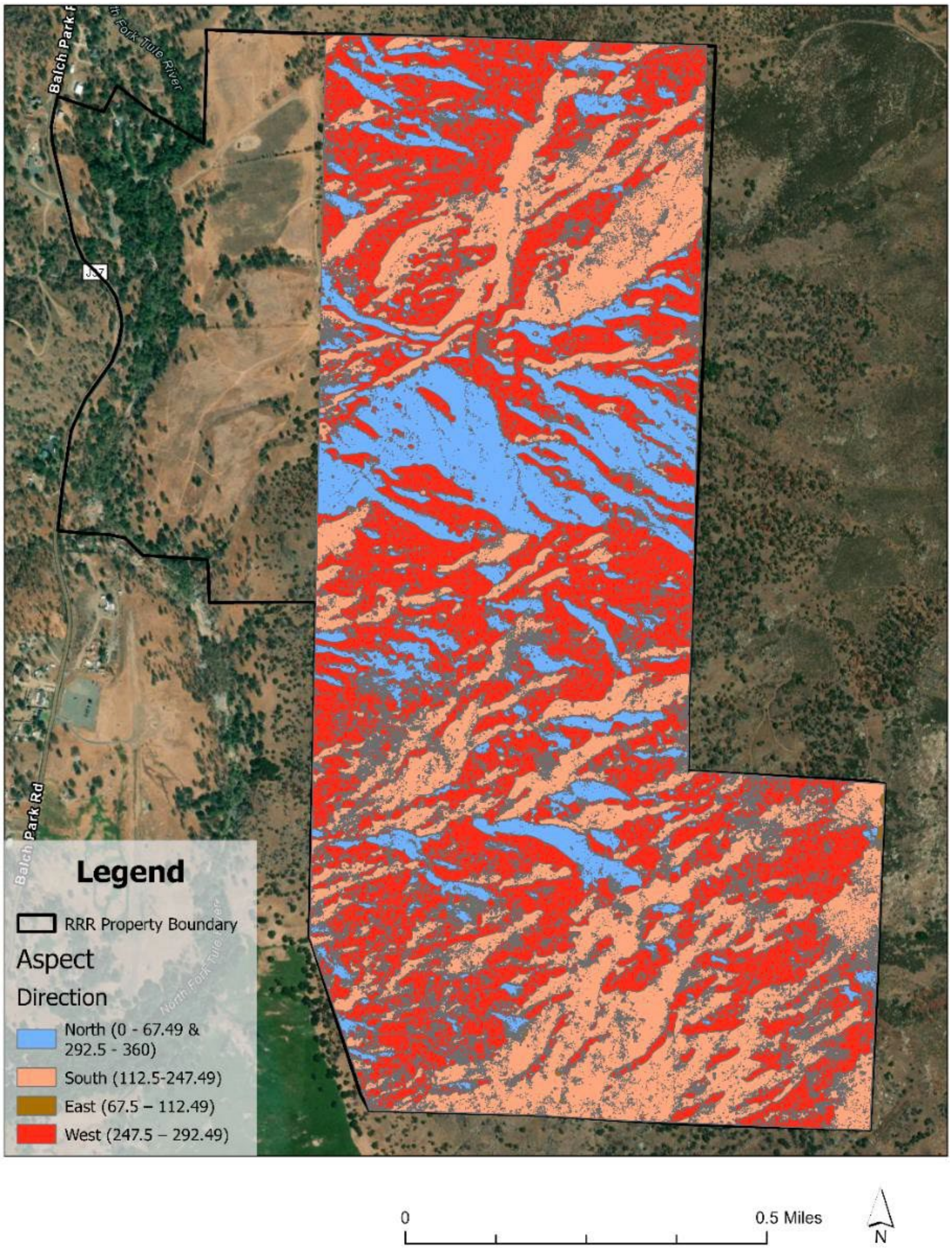

FIGURE 6. Aspect map of River Ridge Ranch, CA.

To determine tree death rates (number of tree deaths/density of trees per block), the 50m^2 sample block was overlaid onto the tree canopy map to calculate tree density per grid block. The density map was overlayed with both the 50 m^2 plots and NDVI layers to quantify the number of dead trees and tree density per 50 m^2 plot (Figure 10).

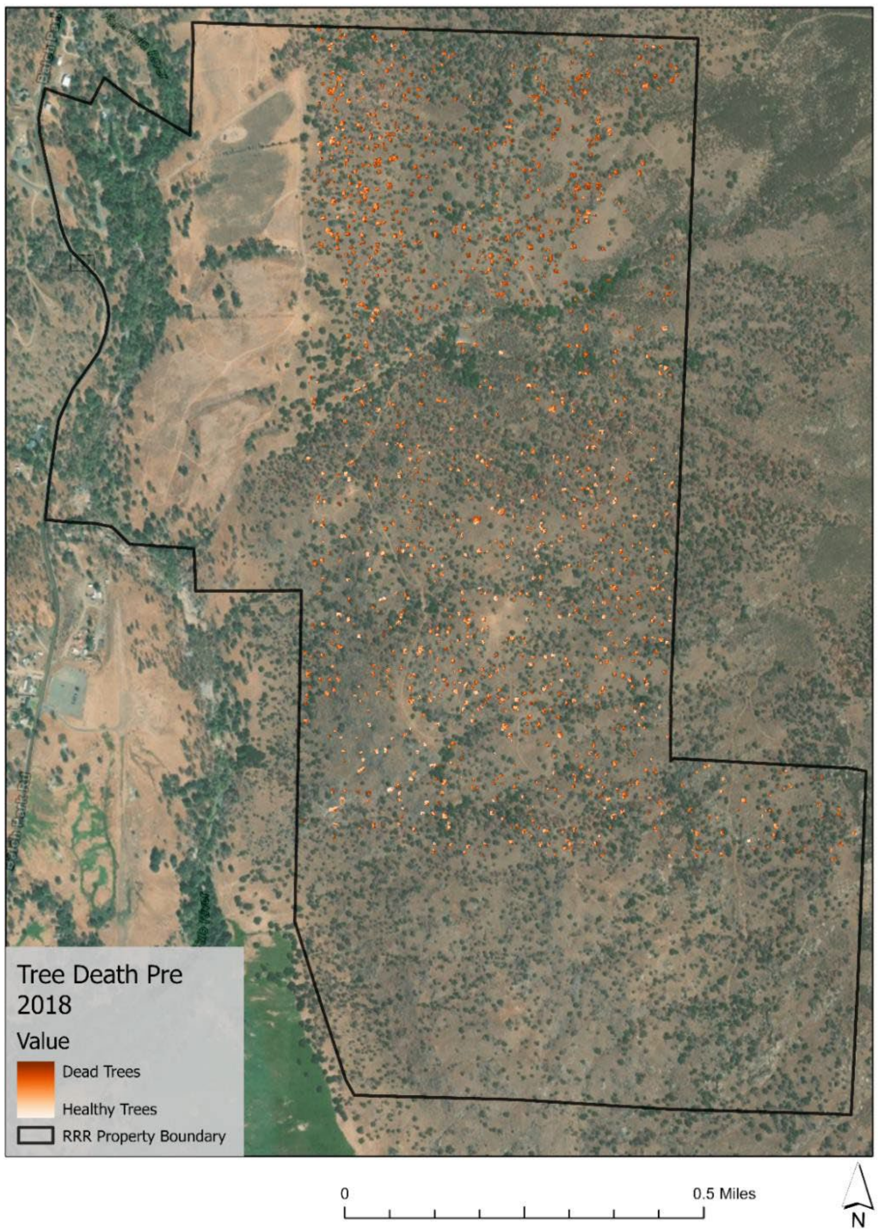

FIGURE 7. Individual tree NDVI values for River Ridge Ranch pre-2018. The "condition color" color scheme was chosen, which used the white and red colors in the spectrum to denote healthy or dead flora, respectively. For the purposes of this study, yellow-marked trees indicate that they were considered stressed, but still alive.

The mortality percentage per plot was calculated by dividing the number of dead trees by the density of all living trees from the 2020 Creer Tree Map product. To determine the slope and aspect class with the highest rate of mortality, the slope and aspect map were generated with their respective class breaks that best represented the terrain of RRR. Mortality percentage per plot were placed in category classes of 0-10 percent, 11-25 percent, 26-50 percent, and 51-100 percent, to compare results from Huesca et al. (2021) study (Figure 10).

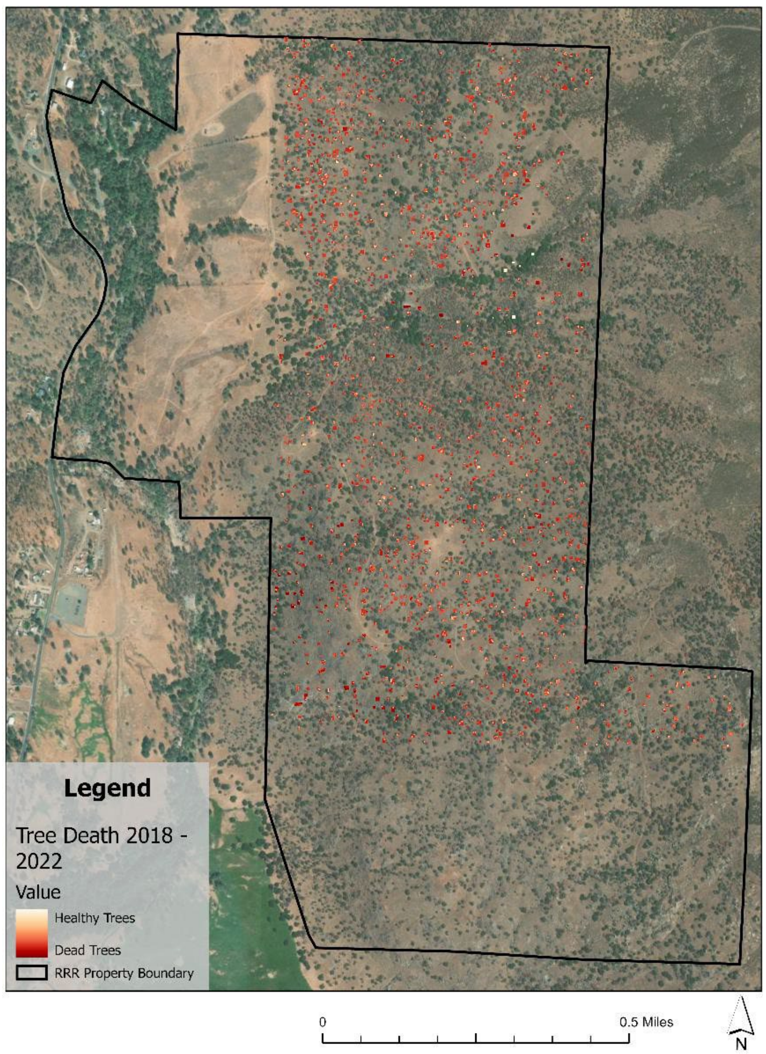

FIGURE 8. Individual tree NDVI values for River Ridge Ranch 2018-2022. The "condition color" color scheme was chosen, which used the white and red colors in the spectrum to denote healthy or dead flora, respectively. For the purposes of this study, yellow-marked trees indicate that they were considered stressed, but still alive.

A data table was constructed to facilitate the calculation of tree mortality metrics. This involved the utilization of the Add Spatial Join tool in ArcGIS Pro, and a spatial join operation was performed between the grid plots and the aspect and slope polygon map products, ensuring that each plot was associated with its corresponding aspect and slope attributes. Subsequently, a secondary set of spatial joins was executed to integrate the Creer individual tree map product, and data from both the pre-2018, and 2018-2022 periods regarding tree mortality. The outcome of this is presented in the data table included in Appendix 1. This data table served as the dataset to calculate tree mortality metrics pertaining to slope and aspect, as seen in Tables 2 and 3.

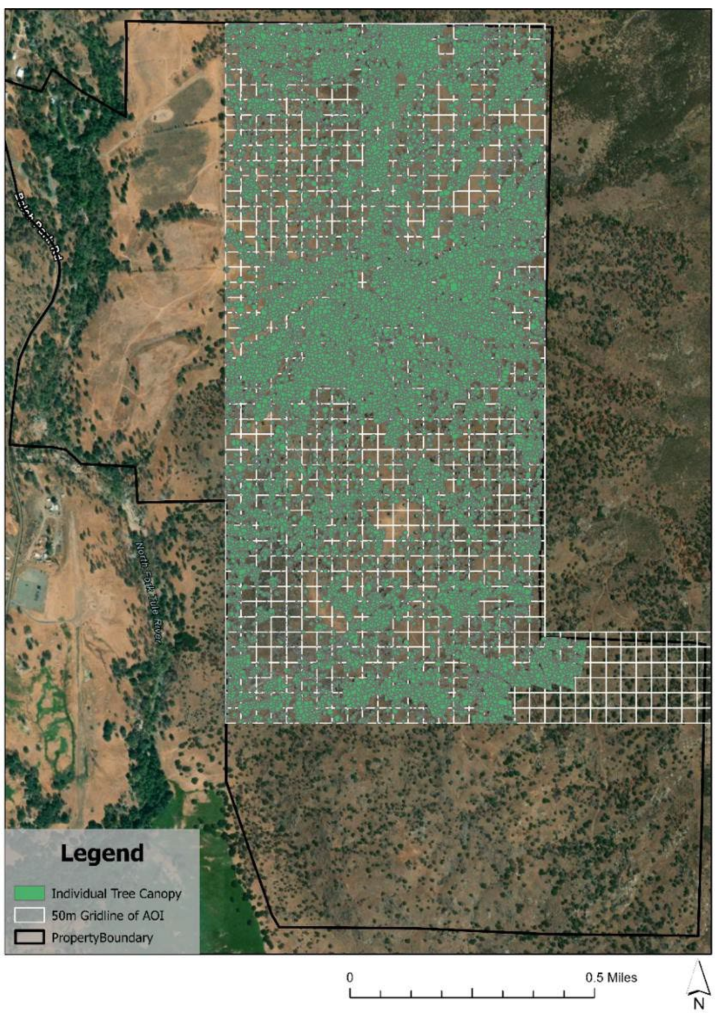

FIGURE 9. Individual tree density map with 50m^2 plots of River Ridge Ranch, CA.

The total population of living trees within each aspect and slope class were calculated by summing the number of living trees from the Creer map product. The total population of deceased trees was calculated by aggregating the pre-2018 and 2018-2022 mortality data within their respective aspect and slope category classes. To get the average number of deceased trees per plot, this count was divided by the total number of plots in each corresponding slope and aspect category. Furthermore, the mortality rate percentage was derived by dividing the total count of deceased trees by the overall population of living trees, as delineated in both Tables 2 and 3.

3.4 Limitations

Worth noting, there were several problems that transpired throughout the duration of conducting this research. Most notably, the locations in which the blue oak mortality field-data was collected in RRR was contingent on how accessible the locale was on foot. Safety was a primary concern, especially as the ranch holds very steep slopes with very little traction. These conditions, along with intense summer heat during the time of data collection, created nontrivial hazard concerns for surveyors. Therefore, the spatial distribution of data may not be entirely representative of the dynamics occurring at RRR. However, this was mitigated as best as possible by visual inspection of the high-resolution data described in the methods section. There were several geographical and methodological scales worth noting. These scales included the scale of an individual tree and tree community at a multiple meter level, the scale of mapping RRR trees using data generated at the centimeter level, the scale of grid cell resolution which imposes a scale on the analysis, the scale imposed by your selecting of 50m2 grids, and the scale of which oak field data collection were conducted at the ranch level. The scale of which an individual tree operates within was assumed to be between the range of 10 to 20 meters for this study. With regards to field data collection, the status of blue oaks has continuously been monitored since early 2019. Due to complications in quality assurance and control, a portion of this dataset was omitted from the mortality analysis while datasets generated in 2020 were primarily used. Despite these issues, it was determined that the map products and datasets produced were satisfactory enough in exploring the relationship of oak mortality and site-specific topography.

CHAPTER 4

RESULTS

To determine whether ecological competition had an impact on tree death, objective 2 determined whether slope and aspect impacted tree mortality even when data are normalized for tree density. The results from the accuracy assessment indicated that the overall accuracy of the algorithm-derived mortality map was below 85%. The low level of accuracy was mainly due to the amount of “double counting”–commission errors where the algorithm had drawn multiple polygons on the same dead trees. To correct for these errors, polygons that referred to the same dead tree were merged to create a single polygon box, reducing the amount of commission errors, and increasing the overall accuracy to 87%. The mortality measures by slope and aspect class are shown in Tables 2 and 3. As can be seen in Table 2, the number of reported tree deaths prior to 2018 on steep slopes and slopes that face west was the highest (618 and 428, respectively), while the number of reported tree deaths on gentle slopes and slopes with a northern orientation was the lowest (10 and 174, respectively). However, when normalized by unit of area, the average number of dead trees per $50m^2$ plot was highest on moderate slopes (3.5). South-facing slopes had the fewest dead trees (2.5), but slopes to the north and west saw the greatest numbers of dead trees per unit area (4.2 and 3.6, respectively). Finally, when adjusted for tree density, moderate slopes had the greatest mortality rate percentage (9.6%), and steep slopes had the lowest (5%). West facing slopes also had the highest mortality rate percentage for aspect, 7.4 percent of deaths occurred on slopes facing west, compared to 5.7 and 6.5 percent for slopes facing north and south. In terms of tree deaths that occurred during the 2018-2022 drought, the number of reported tree deaths on steep slopes and slopes that face west was the highest (1042 and 612, respectively), while the number of reported tree deaths on gentle slopes and slopes with a northern orientation was the lowest (18 and 222, respectively; Table 3).

TABLE 2. Tree Mortality Metrics for Slope and Aspect prior to 2018

Slope Category Class	Total Number of Alive Trees	Total Number of dead trees	Mean Number of Dead Trees per plot*	Death Rate Percentage per plot (*adjusted for density*)
Gentle (0-4.99)	120	10	1	8.3
Moderate (5-9.99)	1984	192	3.5	9.6
Steep (10-19.99)	12344	618	3.4	5
Aspect Category Class				
North (0-67.49 & 292.5-360)	3069	174	4.2	5.7
South (112.5-247.49)	3157	204	2.5	6.5
West (247.5-292.49)	5759	428	3.6	7.4

Note: (Plot = ¼ hectare) River Ridge Ranch, CA.

The average number of dead trees per quarter hectare plot was highest on steep slopes (5.8). South-facing slopes had the fewest dead trees (2.8), but slopes to the north and west had roughly equal numbers of dead trees per area (5.4 and 5.2, respectively). When adjusted for tree density, however, gentle slopes had the greatest mortality rate percentage (15%), and steep slopes had the lowest (8.4%). In addition, 10.6 percent of deaths occurred on slopes facing west, compared to 7.2 and 7.4 percent for slopes facing north and south. West facing slopes also had the highest mortality rate percentage for aspect. The spatial distribution of tree mortality by percentage is shown in Figure 11. Figure 12 highlights the mortality percentage distribution of plots with mortality between 51-100% in pre-2018 and 2018-2022, highlighting the difference in mortality throughout the study period.

TABLE 3. Tree Mortality Metrics for Slope and Aspect 2018-2022

Slope Category Class	Total Number of Alive Trees	Total Number of dead trees	Mean Number of Dead Trees per plot*	Death Rate Percentage per plot (*adjusted for density*)
Gentle (0-4.99)	120	18	1.8	15
Moderate (5-9.99)	1984	238	4.3	12
Steep (10-19.99)	12344	1042	5.8	8.4
Aspect Category Class				
North (0-67.49 & 292.5-360)	3069	222	5.4	7.2
South (112.5-247.49)	3157	233	2.8	7.4
West (247.5 – 292.49)	5759	612	5.2	10.6

Note: (Plot = ¼ hectare) River Ridge Ranch, CA.

We found that in 2018, 2% of the area had high mortality between 51 and 100%, 4% had mortality between 26 and 50%, 18% had mortality between 11 and 25%, 29% had mortality between 1 and 10%, and in 47% no mortality was observed. While in 2022, we found that 3% of the area had high mortality between 51 and 100%, 9% had mortality between 26 and 50%, 22% had mortality between 11 and 25%, 23% had mortality between 1 and 10%, and in 43% no mortality was observed in Table 3. These percentage groups were chosen to compare Huesca's findings, and these results are relatively similar to Huesca et cetera. al's results of mortality percentages within a different test site in the Sierra Nevada. Additionally, this analysis discovered that the RRR's blue oak forests had lost trees since 2018, with an average death rate of 18% throughout that time across all quadrants. These results reveal some patterns to the nature of the mortality distribution, namely that vegetation that were near a valley or regions where water could collect saw less mortality. Additionally, the results show that the percentages of 11%-25%, 26%-50%, and 51%-100% all increased from 2018, suggesting that the most recent drought led more plots to shift to a higher mortality.

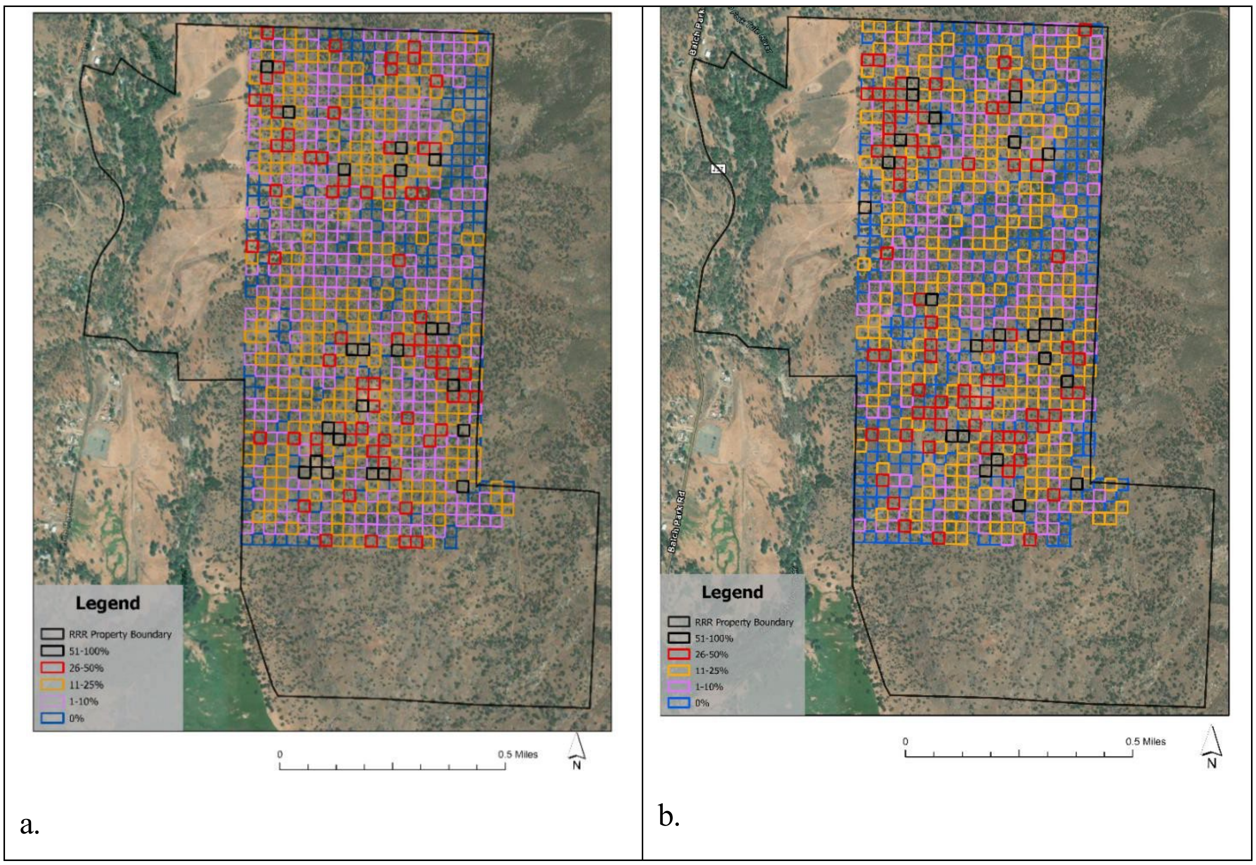

FIGURE 10. The mortality percentage distribution per plot pre-2018 (a) and 2018-2022 (b). Blue plots indicate no mortality, purple plots indicate mortality between 1-10%, orange plots indicate mortality between 11-25%, red plots indicate mortality between 26-50%, and black plots indicate mortality between 51-100%.

TABLE 4. RRR Mortality Percentages vs. Huesca et al. Percentages

Mortality Category per 50x50m plot	Mortality Percentage of Total AOI (2018)	Mortality Percentage of Total AOI (2022)	Huesca et al. Mortality Percentages (2021)
0-10%	76%	66%	51%
11%- 25%	18%	22%	30%
26%-50%	4%	9%	8%
51%-100%	2%	3%	1%

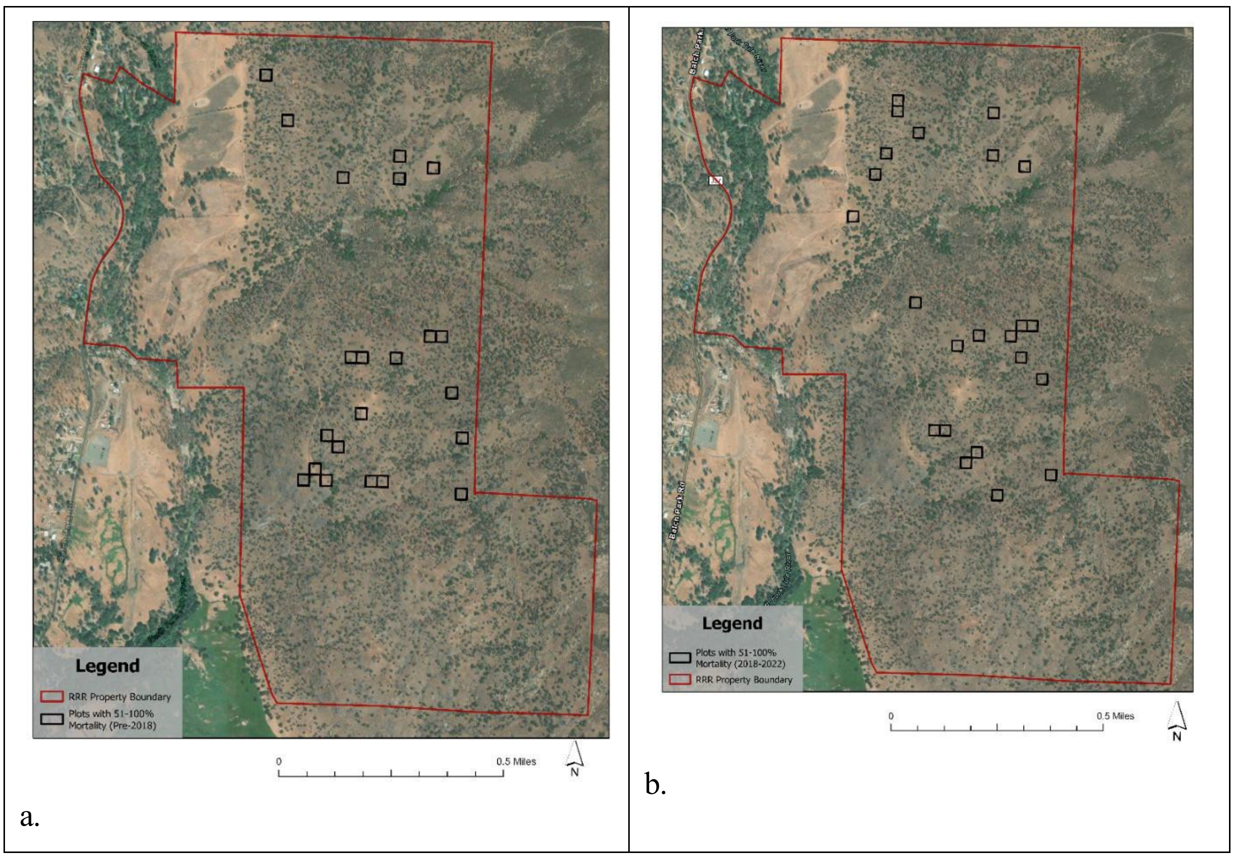

FIGURE 11. The mortality percentage distribution of plots with mortality between 51-100% in pre-2018 (a) and 2018-2022 (b).

CHAPTER 5

DISCUSSION

This study aimed to understand whether topography or ecology (tree density and thus competition for resources) is more influential in the geography of tree death in the southern portion of the Sierra Nevada. This study's main goal was to evaluate the amount of dieback that has happened during the drought of 2018-2022, in order to identify the environmental elements that contribute to or explain tree fatalities. A secondary goal was to contrast the reasons why trees perished between 2018 and 2022 due to drought with reasons why trees died earlier. Our results show that mortality percentages in a different test location in the Sierra Nevada are generally consistent with those found by Huesca et al. Their findings point to some trends in the distribution of mortality, including that vegetation near valleys or areas where water may collect experience lower mortality. The majority of the observed mortality from their study were found in the middle of the percentage ranges, while this study found more mortality at the low and high percentage ranges. This study also found that since 2018, the number of trees in the RRR's blue oak woodlands has dropped, with an overall average death rate of 18 percent across all quadrants over the time period, which further supports the theory that the most recent drought caused more plots to change to a higher death rate.

This study found that when accounting for tree density and steepness, west facing slopes had the greatest death rate percentage, 3.3 percent higher than north and south facing slopes. The most intriguing aspect of the results is how close the death rate percentages were on slopes facing north and south, at 7.2 and 7.4, respectively for the 2018-2022 drought period. These results contradict the hypothesis that tree mortality rates are higher on slopes with a south or southwest orientation as opposed to a north or northwest orientation when accounting for density and steepness.

This study found that when accounting for tree density, gentle slopes had a death rate percentage that was 6.6 percent higher than steeper slopes, contradicting our hypothesis. We would expect steep slopes to have thinner soils and less capacity to support trees during drought. However, the low slope portion of RRR was grazed for over 100 years as cattle prefer gentle slopes, thus grazing and compaction may explain the pattern of mortality observed on the low-lying regions of RRR. Our results suggest that tree mortality rates are higher on slopes with higher tree densities due to competition between different trees and tree species, which supports the hypothesis that tree density ultimately affects mortality to some extent greater than topography. According to our research, 18.3 percent of the trees on an average plot suffered mortality. These findings are comparable to those of two other studies, Das et al. (2020) and Huesca et al. (2021), which looked at the mortality traits of oaks and open woodland regions in other test sites close to the area of interest used in this study. Both studies reported that approximately 23 percent of standing dead trees were found in the southern Sierra Nevada region. However, the Das study did not link tree deaths to a specific period or drought.

This study supports the hypothesis that the 2018-2022 time period had an observable increase in tree mortality. Comparing Tables 2 and 3, death rates for slopes were slightly different compared to 2 periods of pre-2018 and 2018-2022. Pre-2018 had higher mortality on moderate slopes while mortality from the 2018-2022 period was higher on gentler slopes. Death preceded first on moderate slopes and then one gentle ones. This may be due to the fact that it takes several seasons for a tree, especially an oak tree, to die off completely. A possible explanation could be that trees on moderate and steeper slopes may have begun to die off prior to

2018, and trees on more gentler slopes might have started to be stressed for water or resources during the 2018-2022 period. When we compare these two tables, we find that there is more of a temporal pattern of mortality than a clear spatial one.

5.1 Swiecki and Mensing's Model on Blue Oaks

The major theory regarding the current distribution of oak woodlands and the historical events that led up to it was put forth by Mensing and Swiecki in the early 1990s. The lack of recruitment and regeneration of these oaks, which is quite paradoxical considering that this species has adapted to be one of the most drought tolerant oak species, has been a major source of concern for the southern Sierra Nevada and the blue oak woodlands. TJ Swiecki put forth his conceptual model on blue oak regeneration in 1998. Observing that the current rate of sapling recruitment is not high enough to make up for the loss from mortality, he theorized that oak regeneration tends to occur in the best sites in the worst locations and the worst sites in the best locations (Swiecki and Bernhardt 1998). The most xeric locations they looked at were where blue oak saplings were more likely to be found in relatively mesic environments. These included regions with deeper soil, north-facing slopes, and topographical features that tend to concentrate runoff.

Studies conducted in the southern Sierra Nevada generally supported Sweicki's findings on the characteristics of tree mortality in blue oak woodlands. Das investigated oak mortality in Sequoia National Park in 2020 and found that the 2012-2016 drought caused a significant dieback of canopy cover. Das confirmed Sweicki's spatial patterns of death since it revealed a persistent drop in blue oak populations in xeric areas. Williams et al.'s (2015) observation that the drought was most severe in the southern half of the blue oak range led Das to hypothesize that drought-related mortality may also be less severe in more mesic areas. Additionally, Huesca's study from 2021, 75 km south of Das's study site, found that blue oaks on south-facing aspects and in locations with little opportunity for accumulated drainage experienced increased tree death, which was evident at the landscape level. Our study presents a different narrative in that west facing slopes had the highest rate of mortality. The west facing slopes that run the full length of RRR are exposed to more direct solar energy for longer time periods during summer as the setting sun directly faces the steep hillside. It may be that the intense summer sun exposure is more critical to tree mortality than the increased annual insolation received by south-facing slopes.

Scott Mensing proposes that the density and stand structure of oak woodlands today differ from those found before the arrival of the Europeans (1992). Mensing based his work on pollen records collected within the Santa Barbara Basin that suggest relative stability in oak abundance for more than 3 centuries. Mensing discovered that the proportion of oak pollen increased anytime people were present, suggesting that oak woods either grew more widespread or densely during times when either Native peoples or settlers were prevalent. Mensing based his work on an analysis of ethnographic evidence, descriptions of early explorers, and historic records supported by fossil pollen evidence to present the history of land use changes in oak woodlands, which provide a historical account that was supplemental to Swiecki's findings (Mensing 2006). Because they required unburned pasture for grazing animals, settlers had a different perspective on fire than the native Californians did. The age structure and stand density of the BOW that we see now may be explained by the fact that throughout that time, oak recruitment may have increased because of these fire suppression activities. The cumulative findings from Mensing and Sweicki's numerous studies may suggest that the rate of mortality observed in this landscape could be the result of the landscape reverting back to the mean of the historical average stand density, and that the increase of drought conditions may exacerbate the rate of this reversion.

The insights gained from the research of Mensing, Swiecki, and other studies have shed light on the intricate dynamics of blue oak woodlands in the southern Sierra Nevada. The recent dieback observed during the 2012-2018 period, along with the geographic and temporal variations in mortality, further underscores the vulnerability of these woodlands to extreme climatic events. However, as we delve deeper into these complexities, one key takeaway emerges: density ultimately matters more. Scott Mensing's historical perspective, rooted in ethnographic evidence and pollen records, suggests that the current stand structure may be a result of historical land use practices and fire suppression activities, possibly bringing these woodlands back to their historically average stand density. The substantial dieback observed during droughts could signal the potential for increased oak mortality on all slopes in the face of more extreme droughts. Thus, density remains a critical factor in understanding the fate of blue oak woodlands, and Mensing's work provides valuable historical context that informs our understanding of these ecosystems.

CHAPTER 6

CONCLUSION

The spatial distribution of oak woodlands in the Sierra Nevada has experienced tremendous changes over the last few decades (Pile et al. 2019; Das et al. 2020; Dwomoh et al. 2021; Huesca et al. 2021). The composition of these forested and woodland areas may be changing due to the increased intensity and duration of warm temperatures and drought that California experienced from 2010 to 2022, which is leading to an increase in vegetation mortality (Pile et al. 2019; Das et al. 2020; Dwomoh et al. 2021; Huesca et al. 2021). Although a prevailing theory to elucidate mortality remains elusive, Das et al. (2020) point out that the impacts of heightened drought frequency and severity on blue oak woodlands are likely to vary across different locales. It is still unclear whether geography (e.g., varied topography) or ecology (such as tree density and consequent competition) can account for the rate of tree fatalities during drought periods.

Our multiyear vegetation research of tree death throughout a heterogeneous landscape at RRR discovered that topography matters, as tree fatalities were highest on west-facing slopes, contrary to our original expectation of tree mortality being highest on south-facing slopes. When corrected for tree density, gentle slopes exhibited a greater mortality rate than steeper slopes. The drought of 2018-2021 has a considerable influence on RRR's terrain, particularly on gradual slopes, which are not the ranch's toughest topography. Finally, we suggest that high tree density, a legacy of the gold rush era, may explain some of the elevated mortality rates in the dense tree pockets across the RRR study area. To properly understand the changes in the distribution of vegetation on the ranch, a greater understanding of the effects that the local hydrology of RRR has on vegetation in valleys or areas where water can slow down and seep into the soil is necessary. In particular, understanding this type of information is essential to getting a better sense of which ranch locality is performing well. The use of UAV imaging and above-ground field data collection should be expanded in future iterations of this project to include data on soil moisture and mycorrhizal fungi across the ranch. This will help to add deeper layers of understanding to the landscape and identify any potential patterns in mortality and distance to water. Additionally, experiments with historical dating—such as coring trees on RRR—might shed light on the stand age of these oak woodlands and see if they came from the late 1880s.

APPENDIX

MORTALITY ANALYSIS DATA TABLE

MORTALITY ANALYSIS DATA TABLE

Slope Class	Aspect	Alive Trees	Dead Tree Count 2018	Dead Tree Count 2022	Mortality Percentage 2018	Mortality Percentage 2022
Moderate Slope	South	7	0	0	0	0
Moderate Slope	South	14	0	0	0	0
Moderate Slope	South	9	0	0	0	0
Steep Slope	West	21	0	0	0	0
Moderate Slope	East	9	0	0	0	0
Gentle Slope	South	12	0	0	0	0
Gentle Slope	North	6	0	0	0	0
Steep Slope	West	6	2	2	33	33
Steep Slope	South	7	1	1	14	14
Moderate Slope	North	9	2	2	22	22
Steep Slope	South	4	1	2	25	50
Steep Slope	North	3	1	0	33	0
Steep Slope	North	10	0	0	0	0
Moderate Slope	North	14	2	1	14	7
Gentle Slope	East	9	3	1	33	11
Gentle Slope	East	9	3	3	33	33
Moderate Slope	West	9	1	1	11	11
Moderate Slope	West	11	1	0	9	0
Gentle Slope	West	8	0	0	0	0
Gentle Slope	West	19	0	1	0	5
Moderate Slope	East	18	0	0	0	0
Moderate Slope	West	13	1	1	8	8
Moderate Slope	South	14	0	1	0	7
Moderate Slope	South	6	1	2	17	33
Moderate Slope	West	8	0	1	0	12
Moderate Slope	North	12	1	1	8	8
Steep Slope	North	19	0	0	0	0
Steep Slope	North	14	3	3	21	21
Moderate Slope	North	6	0	1	0	17
Steep Slope	North	4	0	0	0	0
Steep Slope	North	13	0	1	0	8
Steep Slope	North	13	1	2	8	15
Moderate Slope	West	16	1	2	6	12
Gentle Slope	West	10	0	2	0	20
Gentle Slope	South	10	1	1	10	10

Moderate Slope	North	15	1	1	7	7
Moderate Slope	East	15	0	1	0	7
Moderate Slope	East	8	0	0	0	0
Gentle Slope	South	19	0	0	0	0
Moderate Slope	East	9	1	0	11	0
Steep Slope	West	8	2	1	25	12
Moderate Slope	South	17	0	0	0	0
Moderate Slope	South	12	0	1	0	8
Moderate Slope	North	12	0	2	0	17
Steep Slope	South	13	1	0	8	0
Steep Slope	North	21	2	1	10	5
Flat Slope	West	9	1	1	11	11
Flat Slope	West	17	0	0	0	0
Steep Slope	West	11	1	1	9	9
Steep Slope	South	16	1	1	6	6
Steep Slope	East	19	0	2	0	11
Moderate Slope	South	17	0	1	0	6
Moderate Slope	West	15	0	0	0	0
Moderate Slope	South	4	0	0	0	0
Moderate Slope	East	16	0	1	0	6
Moderate Slope	North	18	2	2	11	11
Moderate Slope	North	13	0	0	0	0
Moderate Slope	East	9	0	1	0	11
Moderate Slope	South	10	1	1	10	10
Moderate Slope	East	8	0	1	0	12
Steep Slope	North	6	0	1	0	17
Steep Slope	South	20	0	0	0	0
Moderate Slope	South	18	0	0	0	0
Moderate Slope	West	9	2	1	22	11
Moderate Slope	North	5	0	2	0	40
Moderate Slope	West	18	0	0	0	0
Moderate Slope	South	14	4	2	29	14
Moderate Slope	North	15	0	0	0	0
Moderate Slope	East	5	0	0	0	0
Flat Slope	West	7	1	1	14	14
Flat Slope	West	12	0	2	0	17
Steep Slope	South	13	2	1	15	8
Steep Slope	North	19	0	1	0	5
Moderate Slope	North	12	2	1	17	8
Moderate Slope	South	10	1	0	10	0

Moderate Slope	North	5	2	3	40	60
Moderate Slope	North	11	0	0	0	0
Moderate Slope	East	17	0	1	0	6
Moderate Slope	West	22	2	2	9	9
Moderate Slope	North	13	1	1	8	8
Moderate Slope	North	14	1	2	7	14
Moderate Slope	North	12	0	1	0	8
Moderate Slope	West	16	0	0	0	0
Moderate Slope	North	14	0	0	0	0
Moderate Slope	North	7	1	1	14	14
Steep Slope	South	14	0	0	0	0
Moderate Slope	South	9	0	1	0	11
Moderate Slope	South	3	0	0	0	0
Steep Slope	South	19	2	2	11	11
Steep Slope	South	23	0	0	0	0
Steep Slope	West	33	0	0	0	0
Moderate Slope	North	10	2	2	20	20
Moderate Slope	East	23	1	2	4	9
Moderate Slope	North	17	1	0	6	0
Moderate Slope	South	9	3	2	33	22
Steep Slope	South	11	1	0	9	0
Moderate Slope	South	9	0	2	0	22
Moderate Slope	West	12	0	1	0	8
Gentle Slope	North	12	0	1	0	8
Gentle Slope	West	9	1	1	11	11
Moderate Slope	East	14	3	3	21	21
Moderate Slope	South	18	3	1	17	6
Moderate Slope	North	6	1	2	17	33
Moderate Slope	South	10	1	1	10	10
Moderate Slope	West	10	0	0	0	0
Moderate Slope	South	17	0	0	0	0
Steep Slope	South	15	0	1	0	7
Moderate Slope	South	8	1	0	12	0
Moderate Slope	East	10	1	1	10	10
Moderate Slope	East	12	0	0	0	0
Steep Slope	South	12	0	0	0	0
Steep Slope	North	5	1	2	20	40
Steep Slope	South	42	2	2	5	5
Moderate Slope	North	23	2	2	9	9
Moderate Slope	South	4	0	1	0	25

Moderate Slope	West	17	1	1	6	6
Flat Slope	West	20	0	0	0	0
Gentle Slope	South	11	2	1	18	9
Steep Slope	South	13	0	2	0	15
Steep Slope	South	6	0	0	0	0
Moderate Slope	South	6	1	0	17	0
Gentle Slope	East	19	0	0	0	0
Gentle Slope	North	9	1	1	11	11
Moderate Slope	West	11	1	2	9	18
Moderate Slope	South	15	2	2	13	13
Steep Slope	North	15	1	1	7	7
Moderate Slope	South	9	0	0	0	0
Moderate Slope	North	3	3	2	100	67
Moderate Slope	South	4	0	0	0	0
Moderate Slope	North	15	0	0	0	0
Steep Slope	West	10	2	2	20	20
Moderate Slope	East	5	0	0	0	0
Steep Slope	East	18	0	0	0	0
Steep Slope	South	9	0	1	0	11
Steep Slope	West	7	1	1	14	14
Steep Slope	North	4	1	1	25	25
Moderate Slope	South	7	0	0	0	0
Moderate Slope	South	2	2	1	100	50
Gentle Slope	South	7	1	1	14	14
Flat Slope	South	1	1	0	100	0
Gentle Slope	North	14	2	2	14	14
Moderate Slope	West	16	0	0	0	0
Moderate Slope	South	12	0	1	0	8
Moderate Slope	South	3	2	2	67	67
Moderate Slope	South	1	1	0	100	0
Gentle Slope	East	3	1	1	33	33
Moderate Slope	West	26	1	0	4	0
Moderate Slope	West	15	0	2	0	13
Moderate Slope	North	13	1	1	8	8
Moderate Slope	North	10	0	0	0	0
Moderate Slope	North	14	2	2	14	14
Moderate Slope	North	3	0	0	0	0
Moderate Slope	North	5	1	1	20	20
Steep Slope	North	9	1	1	11	11
Steep Slope	South	4	0	0	0	0

Steep Slope	South	12	0	0	0	0
Steep Slope	North	5	1	0	20	0
Steep Slope	South	7	0	0	0	0
Gentle Slope	South	5	0	0	0	0
Gentle Slope	East	1	2	0	200	0
Gentle Slope	South	10	1	1	10	10
Gentle Slope	North	12	0	0	0	0
Moderate Slope	East	19	2	3	11	16
Moderate Slope	South	11	0	0	0	0
Moderate Slope	West	14	1	1	7	7
Gentle Slope	West	3	1	2	33	67
Moderate Slope	North	9	1	1	11	11
Moderate Slope	South	7	0	2	0	29
Moderate Slope	West	15	0	0	0	0
Moderate Slope	East	16	0	2	0	12
Moderate Slope	North	13	0	2	0	15
Moderate Slope	East	18	2	0	11	0
Moderate Slope	East	19	1	2	5	11
Moderate Slope	West	2	0	1	0	50
Steep Slope	South	17	2	2	12	12
Steep Slope	North	5	1	0	20	0
Steep Slope	North	10	0	0	0	0
Steep Slope	South	10	2	2	20	20
Moderate Slope	South	3	0	0	0	0
Gentle Slope	North	2	0	1	0	50
Gentle Slope	North	10	3	3	30	30
Moderate Slope	South	15	2	3	13	20
Gentle Slope	South	8	0	0	0	0
Moderate Slope	East	14	2	2	14	14
Moderate Slope	North	13	3	2	23	15
Moderate Slope	South	11	3	4	27	36
Gentle Slope	West	15	3	1	20	7
Gentle Slope	North	12	1	2	8	17
Steep Slope	East	10	1	1	10	10
Steep Slope	West	20	1	1	5	5
Moderate Slope	West	15	0	2	0	13
Moderate Slope	South	16	1	1	6	6
Moderate Slope	West	9	2	2	22	22
Steep Slope	North	13	2	0	15	0
Steep Slope	East	5	1	0	20	0

Steep Slope	South	13	1	2	8	15
Steep Slope	North	7	3	2	43	29
Steep Slope	West	10	1	2	10	20
Steep Slope	North	9	0	1	0	11
Moderate Slope	South	7	2	2	29	29
Moderate Slope	South	4	0	2	0	50
Gentle Slope	South	4	2	1	50	25
Gentle Slope	South	10	0	1	0	10
Gentle Slope	South	3	3	3	100	100
Moderate Slope	North	8	3	5	38	62
Moderate Slope	East	11	2	0	18	0
Moderate Slope	West	6	0	1	0	17
Moderate Slope	North	7	2	2	29	29
Moderate Slope	North	7	1	3	14	43
Steep Slope	South	6	1	2	17	33
Steep Slope	South	12	0	0	0	0
Moderate Slope	West	5	2	1	40	20
Moderate Slope	West	5	0	0	0	0
Moderate Slope	East	22	2	1	9	5
Steep Slope	North	21	1	2	5	10
Steep Slope	South	5	0	0	0	0
Steep Slope	North	12	2	0	17	0
Steep Slope	South	10	1	1	10	10
Steep Slope	West	6	0	0	0	0
Steep Slope	West	1	0	0	0	0
Steep Slope	North	16	2	2	12	12
Moderate Slope	North	7	1	1	14	14
Gentle Slope	West	6	1	0	17	0
Gentle Slope	South	3	2	1	67	33
Gentle Slope	North	4	2	2	50	50
Gentle Slope	North	9	0	0	0	0
Gentle Slope	West	11	3	4	27	36
Moderate Slope	East	10	1	1	10	10
Moderate Slope	North	8	1	0	12	0
Moderate Slope	North	6	0	0	0	0
Moderate Slope	South	8	1	0	12	0
Steep Slope	South	10	0	1	0	10
Moderate Slope	West	5	0	2	0	40
Moderate Slope	North	5	2	1	40	20
Steep Slope	South	3	0	0	0	0

Steep Slope	West	3	2	0	67	0
Steep Slope	North	9	1	1	11	11
Steep Slope	North	20	1	2	5	10
Steep Slope	North	17	1	1	6	6
Steep Slope	North	18	1	1	6	6
Steep Slope	South	11	0	0	0	0
Steep Slope	West	10	0	0	0	0
Moderate Slope	East	11	1	3	9	27
Moderate Slope	South	8	2	3	25	38
Moderate Slope	East	12	2	1	17	8
Moderate Slope	South	8	0	2	0	25
Gentle Slope	East	10	2	2	20	20
Gentle Slope	East	6	0	1	0	17
Moderate Slope	South	12	0	1	0	8
Moderate Slope	East	12	2	2	17	17
Moderate Slope	North	19	1	1	5	5
Moderate Slope	South	7	2	0	29	0
Steep Slope	South	3	0	1	0	33
Moderate Slope	North	8	0	2	0	25
Moderate Slope	South	8	1	3	12	38
Steep Slope	North	11	2	1	18	9
Steep Slope	South	19	1	1	5	5
Steep Slope	West	15	0	0	0	0
Moderate Slope	West	19	1	1	5	5
Steep Slope	North	16	1	2	6	12
Steep Slope	South	19	1	0	5	0
Steep Slope	North	9	2	1	22	11
Steep Slope	North	15	0	1	0	7
Steep Slope	East	18	3	0	17	0
Steep Slope	West	14	0	0	0	0
Moderate Slope	North	14	3	4	21	29
Moderate Slope	North	14	3	3	21	21
Gentle Slope	West	12	3	4	25	33
Flat Slope	West	5	3	2	60	40
Gentle Slope	West	3	1	1	33	33
Gentle Slope	North	6	1	1	17	17
Moderate Slope	North	7	0	1	0	14
Moderate Slope	South	14	0	1	0	7
Moderate Slope	North	5	0	1	0	20
Moderate Slope	South	12	0	0	0	0

Steep Slope	East	6	1	1	17	17
Moderate Slope	East	6	1	1	17	17
Steep Slope	East	14	3	3	21	21
Steep Slope	South	14	1	1	7	7
Moderate Slope	East	14	0	0	0	0
Steep Slope	North	16	0	0	0	0
Steep Slope	West	16	2	2	12	12
Steep Slope	North	17	0	0	0	0
Steep Slope	West	7	1	1	14	14
Moderate Slope	North	8	2	3	25	38
Moderate Slope	East	17	0	0	0	0
Moderate Slope	North	11	0	0	0	0
Steep Slope	South	14	3	3	21	21
Gentle Slope	West	8	1	3	12	38
Flat Slope	East	2	1	1	50	50
Gentle Slope	East	1	0	0	0	0
Gentle Slope	South	4	1	1	25	25
Moderate Slope	North	9	0	1	0	11
Moderate Slope	South	10	1	2	10	20
Gentle Slope	East	13	1	2	8	15
Moderate Slope	South	12	1	1	8	8
Steep Slope	West	12	1	2	8	17
Moderate Slope	North	3	1	1	33	33
Steep Slope	East	7	2	2	29	29
Steep Slope	South	6	3	3	50	50
Moderate Slope	North	8	0	0	0	0
Steep Slope	West	24	0	0	0	0
Steep Slope	East	12	1	1	8	8
Moderate Slope	South	11	1	1	9	9
Moderate Slope	North	10	2	2	20	20
Moderate Slope	North	15	1	2	7	13
Moderate Slope	South	14	1	0	7	0
Moderate Slope	North	20	0	2	0	10
Moderate Slope	North	16	1	0	6	0
Gentle Slope	North	7	1	1	14	14
Flat Slope	South	6	3	1	50	17
Flat Slope	South	7	2	2	29	29
Gentle Slope	South	12	3	4	25	33
Moderate Slope	North	14	1	2	7	14
Moderate Slope	South	10	0	0	0	0

Moderate Slope	East	16	0	1	0	6
Steep Slope	North	16	1	1	6	6
Steep Slope	South	8	2	4	25	50
Steep Slope	South	7	4	4	57	57
Steep Slope	North	11	0	2	0	18
Steep Slope	North	20	1	2	5	10
Steep Slope	West	9	0	0	0	0
Steep Slope	South	10	0	1	0	10
Steep Slope	East	13	1	1	8	8
Moderate Slope	North	16	1	1	6	6
Moderate Slope	North	3	0	0	0	0
Moderate Slope	North	11	0	0	0	0
Moderate Slope	East	6	0	1	0	17
Moderate Slope	East	12	1	3	8	25
Moderate Slope	North	10	0	0	0	0
Flat Slope	North	14	0	1	0	7
Flat Slope	North	10	0	0	0	0
Flat Slope	West	8	0	0	0	0
Gentle Slope	West	11	1	0	9	0
Moderate Slope	West	12	1	1	8	8
Moderate Slope	North	5	0	0	0	0
Moderate Slope	North	5	0	1	0	20
Steep Slope	South	9	0	1	0	11
Steep Slope	North	11	3	2	27	18
Moderate Slope	North	9	0	0	0	0
Moderate Slope	South	6	2	3	33	50
Steep Slope	North	16	4	2	25	12
Moderate Slope	North	10	0	1	0	10
Moderate Slope	South	7	1	2	14	29
Steep Slope	North	9	1	3	11	33
Moderate Slope	North	12	1	1	8	8
Moderate Slope	South	7	1	1	14	14
Moderate Slope	South	9	1	0	11	0
Moderate Slope	North	6	1	2	17	33
Moderate Slope	West	6	3	3	50	50
Moderate Slope	South	4	1	0	25	0
Moderate Slope	West	5	1	0	20	0
Gentle Slope	West	6	1	1	17	17
Moderate Slope	South	13	1	0	8	0
Moderate Slope	North	15	1	1	7	7

Moderate Slope	North	11	2	1	18	9
Gentle Slope	North	12	1	1	8	8
Steep Slope	South	5	2	3	40	60
Steep Slope	South	8	1	1	12	12
Steep Slope	East	8	0	0	0	0
Moderate Slope	South	7	1	3	14	43
Steep Slope	South	6	0	0	0	0
Moderate Slope	North	8	0	0	0	0
Moderate Slope	West	9	0	1	0	11
Moderate Slope	North	17	1	2	6	12
Moderate Slope	South	11	1	0	9	0
Moderate Slope	North	15	0	0	0	0
Moderate Slope	South	6	1	1	17	17
Steep Slope	East	11	0	3	0	27
Moderate Slope	North	3	0	0	0	0
Moderate Slope	West	12	1	1	8	8
Moderate Slope	West	1	1	0	100	0
Moderate Slope	West	1	1	3	100	300
Moderate Slope	North	8	2	3	25	38
Moderate Slope	South	10	0	0	0	0
Moderate Slope	East	6	4	3	67	50
Moderate Slope	East	11	3	2	27	18
Gentle Slope	North	10	0	0	0	0
Moderate Slope	South	6	2	1	33	17
Steep Slope	North	4	2	1	50	25
Steep Slope	South	5	2	2	40	40
Steep Slope	South	16	1	1	6	6
Steep Slope	East	19	0	1	0	5
Moderate Slope	West	7	1	1	14	14
Moderate Slope	West	11	2	2	18	18
Moderate Slope	East	4	0	0	0	0
Moderate Slope	South	13	0	0	0	0
Moderate Slope	East	4	0	2	0	50
Moderate Slope	North	11	0	0	0	0
Steep Slope	North	10	2	2	20	20
Steep Slope	East	10	1	0	10	0
Steep Slope	West	9	3	2	33	22
Steep Slope	South	9	1	1	11	11
Gentle Slope	East	9	0	0	0	0
Gentle Slope	West	11	0	0	0	0

Moderate Slope	South	5	0	4	0	80
Moderate Slope	North	10	4	4	40	40
Moderate Slope	North	2	0	0	0	0
Moderate Slope	West	5	2	3	40	60
Moderate Slope	South	10	0	2	0	20
Moderate Slope	North	9	0	2	0	22
Steep Slope	North	12	0	0	0	0
Steep Slope	South	9	2	2	22	22
Steep Slope	West	14	0	0	0	0
Gentle Slope	East	10	1	1	10	10
Gentle Slope	North	6	1	1	17	17
Moderate Slope	South	6	0	0	0	0
Moderate Slope	West	18	0	0	0	0
Moderate Slope	West	8	2	0	25	0
Moderate Slope	South	10	1	3	10	30
Steep Slope	South	9	1	2	11	22
Steep Slope	North	10	0	0	0	0
Moderate Slope	South	2	0	0	0	0
Moderate Slope	East	12	2	1	17	8
Steep Slope	West	10	1	1	10	10
Steep Slope	West	13	1	1	8	8
Steep Slope	North	9	0	1	0	11
Moderate Slope	West	9	1	0	11	0
Moderate Slope	North	10	2	2	20	20
Moderate Slope	South	2	2	3	100	150
Moderate Slope	North	1	1	1	100	100
Moderate Slope	West	10	1	0	10	0
Moderate Slope	East	11	0	0	0	0
Moderate Slope	South	13	2	2	15	15
Moderate Slope	West	12	0	1	0	8
Moderate Slope	South	17	0	0	0	0
Gentle Slope	South	12	1	1	8	8
Gentle Slope	North	16	0	0	0	0
Moderate Slope	South	11	1	1	9	9
Moderate Slope	East	12	0	0	0	0
Moderate Slope	North	9	0	2	0	22
Steep Slope	South	8	0	1	0	12
Steep Slope	West	17	0	0	0	0
Moderate Slope	East	14	2	1	14	7
Moderate Slope	East	17	2	1	12	6

Steep Slope	West	12	0	0	0	0
Steep Slope	West	16	1	0	6	0
Steep Slope	East	13	0	1	0	8
Steep Slope	East	16	1	2	6	12
Steep Slope	West	10	3	2	30	20
Moderate Slope	East	12	3	1	25	8
Moderate Slope	South	9	1	2	11	22
Moderate Slope	South	13	0	1	0	8
Steep Slope	West	9	0	0	0	0
Moderate Slope	North	15	1	1	7	7
Steep Slope	South	19	1	0	5	0
Moderate Slope	West	13	2	1	15	8
Moderate Slope	West	14	1	3	7	21
Moderate Slope	West	13	0	0	0	0
Moderate Slope	South	20	0	1	0	5
Moderate Slope	North	9	2	3	22	33
Moderate Slope	North	6	1	6	17	100
Moderate Slope	West	9	0	0	0	0
Steep Slope	West	14	2	2	14	14
Steep Slope	West	13	0	0	0	0
Steep Slope	East	16	0	1	0	6
Steep Slope	West	22	0	1	0	5
Steep Slope	South	17	0	0	0	0
Steep Slope	South	10	0	0	0	0
Steep Slope	West	11	2	1	18	9
Moderate Slope	East	17	1	3	6	18
Steep Slope	East	12	0	1	0	8
Moderate Slope	West	12	2	3	17	25
Moderate Slope	West	14	1	1	7	7
Steep Slope	North	15	1	0	7	0
Steep Slope	North	20	2	1	10	5
Moderate Slope	South	18	0	0	0	0
Steep Slope	South	11	0	1	0	9
Moderate Slope	South	17	0	1	0	6
Moderate Slope	West	9	0	1	0	11
Steep Slope	West	14	1	2	7	14
Moderate Slope	West	20	3	2	15	10
Moderate Slope	South	15	1	2	7	13
Moderate Slope	South	18	1	2	6	11
Steep Slope	East	14	1	1	7	7

Steep Slope	West	19	2	1	11	5
Moderate Slope	East	16	0	2	0	12
Moderate Slope	West	14	0	0	0	0
Steep Slope	West	14	2	2	14	14
Steep Slope	East	16	1	0	6	0
Steep Slope	South	13	2	1	15	8
Moderate Slope	West	13	1	1	8	8
Steep Slope	West	14	1	1	7	7
Moderate Slope	West	15	1	1	7	7
Steep Slope	East	7	1	1	14	14
Steep Slope	East	13	2	1	15	8
Steep Slope	West	14	1	1	7	7
Gentle Slope	East	10	0	0	0	0
Steep Slope	West	14	0	0	0	0
Moderate Slope	West	13	0	0	0	0
Moderate Slope	South	8	1	1	12	12
Moderate Slope	West	16	0	1	0	6
Steep Slope	West	14	0	1	0	7
Steep Slope	South	13	0	1	0	8
Steep Slope	East	16	0	2	0	12
Steep Slope	West	13	1	1	8	8
Moderate Slope	West	15	0	0	0	0
Moderate Slope	South	14	0	0	0	0
Moderate Slope	North	11	0	0	0	0
Moderate Slope	West	17	0	0	0	0
Steep Slope	South	18	0	0	0	0
Steep Slope	East	17	0	0	0	0
Steep Slope	West	17	0	1	0	6
Steep Slope	West	19	1	3	5	16
Steep Slope	West	19	0	1	0	5
Steep Slope	West	10	2	2	20	20
Steep Slope	South	11	0	0	0	0
Steep Slope	South	10	0	0	0	0
Flat Slope	South	5	0	1	0	20
Gentle Slope	South	13	0	0	0	0
Moderate Slope	North	17	0	1	0	6
Moderate Slope	East	14	0	0	0	0
Moderate Slope	North	13	1	1	8	8
Steep Slope	West	15	1	1	7	7
Steep Slope	South	12	0	0	0	0

Moderate Slope	West	20	0	0	0	0
Moderate Slope	West	18	0	0	0	0
Moderate Slope	West	15	1	1	7	7
Moderate Slope	North	13	0	1	0	8
Moderate Slope	South	17	0	0	0	0
Moderate Slope	West	11	1	1	9	9
Moderate Slope	East	13	1	0	8	0
Moderate Slope	South	12	1	1	8	8
Moderate Slope	East	16	1	0	6	0
Steep Slope	East	14	0	0	0	0
Steep Slope	East	12	0	1	0	8
Steep Slope	South	15	1	1	7	7
Steep Slope	West	22	0	0	0	0
Steep Slope	South	7	0	0	0	0
Gentle Slope	East	6	1	0	17	0
Gentle Slope	North	9	0	0	0	0
Gentle Slope	West	6	2	2	33	33
Moderate Slope	West	12	2	1	17	8
Steep Slope	West	15	2	1	13	7
Steep Slope	West	15	0	0	0	0
Steep Slope	West	14	0	1	0	7
Moderate Slope	North	12	1	2	8	17
Moderate Slope	East	15	0	1	0	7
Moderate Slope	West	14	0	0	0	0
Moderate Slope	South	9	0	0	0	0
Moderate Slope	West	10	0	1	0	10
Moderate Slope	North	13	0	0	0	0
Moderate Slope	West	7	3	0	43	0
Moderate Slope	South	18	1	3	6	17
Gentle Slope	West	18	0	0	0	0
Gentle Slope	North	16	0	0	0	0
Moderate Slope	South	10	1	3	10	30
Steep Slope	East	15	0	0	0	0
Moderate Slope	South	12	1	1	8	8
Steep Slope	South	17	0	0	0	0
Flat Slope	North	6	2	3	33	50
Flat Slope	West	11	0	0	0	0
Gentle Slope	West	14	0	0	0	0
Gentle Slope	North	16	1	1	6	6
Gentle Slope	East	10	0	1	0	10

Moderate Slope	East	20	0	1	0	5
Steep Slope	West	16	0	2	0	12
Moderate Slope	West	17	0	0	0	0
Moderate Slope	East	17	0	0	0	0
Moderate Slope	South	14	1	1	7	7
Moderate Slope	North	17	2	2	12	12
Moderate Slope	North	13	1	2	8	15
Moderate Slope	West	13	2	3	15	23
Moderate Slope	West	14	0	0	0	0
Moderate Slope	East	20	0	0	0	0
Moderate Slope	North	13	0	0	0	0
Moderate Slope	East	19	0	0	0	0
Moderate Slope	West	17	0	1	0	6
Moderate Slope	South	17	0	0	0	0
Steep Slope	South	9	0	0	0	0
Steep Slope	South	12	1	0	8	0
Flat Slope	North	7	0	0	0	0
Flat Slope	East	3	0	0	0	0
Flat Slope	East	7	0	1	0	14
Gentle Slope	North	13	1	0	8	0
Gentle Slope	East	10	1	0	10	0
Gentle Slope	North	9	1	0	11	0
Gentle Slope	East	11	0	1	0	9
Moderate Slope	North	25	0	1	0	4
Steep Slope	South	22	0	0	0	0
Moderate Slope	South	13	0	0	0	0
Moderate Slope	East	14	0	1	0	7
Moderate Slope	West	14	0	0	0	0
Gentle Slope	South	14	0	2	0	14
Gentle Slope	East	15	0	0	0	0
Moderate Slope	South	21	0	0	0	0
Moderate Slope	West	12	2	0	17	0
Moderate Slope	North	11	0	0	0	0
Moderate Slope	South	18	0	1	0	6
Moderate Slope	South	13	0	0	0	0
Steep Slope	South	15	2	1	13	7
Steep Slope	North	10	2	0	20	0
Flat Slope	South	9	0	0	0	0
Flat Slope	South	10	0	0	0	0
Gentle Slope	East	11	1	2	9	18

Moderate Slope	South	11	1	2	9	18
Gentle Slope	South	15	0	1	0	7
Gentle Slope	West	13	1	1	8	8
Gentle Slope	East	20	0	0	0	0
Gentle Slope	North	13	0	1	0	8
Gentle Slope	West	14	1	2	7	14
Moderate Slope	East	10	0	1	0	10
Moderate Slope	East	16	1	1	6	6
Moderate Slope	North	11	0	0	0	0
Moderate Slope	South	16	0	0	0	0
Gentle Slope	North	16	0	2	0	12
Moderate Slope	East	12	0	1	0	8
Moderate Slope	East	14	0	2	0	14
Moderate Slope	South	15	0	0	0	0
Gentle Slope	East	10	0	1	0	10
Moderate Slope	West	17	1	0	6	0
Steep Slope	West	12	0	0	0	0
Steep Slope	West	12	0	0	0	0
Flat Slope	East	1	0	1	0	100
Gentle Slope	North	1	0	0	0	0
Gentle Slope	North	9	0	0	0	0
Gentle Slope	North	14	1	2	7	14
Gentle Slope	East	20	0	0	0	0
Moderate Slope	East	18	0	0	0	0
Gentle Slope	West	16	0	1	0	6
Gentle Slope	North	15	0	0	0	0
Gentle Slope	North	4	1	1	25	25
Moderate Slope	South	10	0	0	0	0
Moderate Slope	West	18	0	0	0	0
Gentle Slope	West	20	0	0	0	0
Moderate Slope	South	17	0	1	0	6
Moderate Slope	South	18	0	0	0	0
Moderate Slope	East	11	0	0	0	0
Moderate Slope	South	17	2	3	12	18
Moderate Slope	South	18	0	0	0	0
Gentle Slope	West	13	0	1	0	8
Gentle Slope	North	14	0	3	0	21
Steep Slope	South	15	1	0	7	0
Steep Slope	South	12	0	0	0	0
Flat Slope	West	1	0	0	0	0

Flat Slope	East	13	0	0	0	0
Gentle Slope	West	11	1	1	9	9
Gentle Slope	South	21	3	2	14	10
Gentle Slope	East	8	0	0	0	0
Moderate Slope	West	11	0	1	0	9
Moderate Slope	South	13	0	3	0	23
Moderate Slope	West	17	0	1	0	6
Moderate Slope	North	14	1	0	7	0
Moderate Slope	South	14	1	1	7	7
Moderate Slope	West	17	0	0	0	0
Moderate Slope	South	20	0	0	0	0
Moderate Slope	West	16	2	1	12	6
Moderate Slope	East	13	0	0	0	0
Moderate Slope	South	12	0	1	0	8
Moderate Slope	West	14	0	1	0	7
Moderate Slope	South	8	0	1	0	12
Moderate Slope	North	17	0	0	0	0
Moderate Slope	South	21	0	0	0	0
Steep Slope	North	17	0	0	0	0
Steep Slope	South	6	0	0	0	0
Flat Slope	East	11	0	0	0	0
Flat Slope	East	5	0	0	0	0
Gentle Slope	South	7	3	1	43	14
Gentle Slope	North	10	0	3	0	30
Gentle Slope	North	6	0	0	0	0
Moderate Slope	South	9	0	0	0	0
Moderate Slope	North	14	0	0	0	0
Steep Slope	South	7	3	1	43	14
Moderate Slope	West	15	0	0	0	0
Moderate Slope	West	18	0	0	0	0
Gentle Slope	West	14	4	2	29	14
Moderate Slope	West	9	1	0	11	0
Moderate Slope	North	6	3	1	50	17
Moderate Slope	West	13	0	0	0	0
Moderate Slope	East	5	2	1	40	20
Moderate Slope	South	7	2	1	29	14
Moderate Slope	South	16	0	0	0	0
Moderate Slope	South	18	0	0	0	0
Moderate Slope	East	14	0	1	0	7
Steep Slope	East	8	0	2	0	25

Steep Slope	South	11	0	1	0	9
Flat Slope	East	5	0	0	0	0
Gentle Slope	East	1	0	0	0	0
Moderate Slope	East	17	0	2	0	12
Gentle Slope	West	10	1	3	10	30
Gentle Slope	East	5	0	1	0	20
Moderate Slope	North	10	0	0	0	0
Steep Slope	South	10	0	1	0	10
Steep Slope	South	7	0	1	0	14
Moderate Slope	North	8	4	1	50	12
Moderate Slope	North	15	1	2	7	13
Gentle Slope	East	11	2	1	18	9
Moderate Slope	South	19	4	1	21	5
Moderate Slope	West	10	5	5	50	50
Moderate Slope	North	8	2	2	25	25
Moderate Slope	North	11	1	0	9	0
Steep Slope	East	19	0	0	0	0
Gentle Slope	West	14	1	1	7	7
Moderate Slope	West	22	0	0	0	0
Moderate Slope	North	15	0	0	0	0
Moderate Slope	North	18	0	0	0	0
Steep Slope	South	15	0	0	0	0
Flat Slope	East	7	0	1	0	14
Gentle Slope	North	9	1	2	11	22
Moderate Slope	East	7	1	4	14	57
Moderate Slope	South	13	0	5	0	38
Gentle Slope	West	7	0	1	0	14
Moderate Slope	East	10	0	1	0	10
Steep Slope	North	10	0	0	0	0
Steep Slope	North	8	0	0	0	0
Steep Slope	West	2	2	0	100	0
Gentle Slope	South	10	2	3	20	30
Moderate Slope	West	14	3	3	21	21
Moderate Slope	South	11	1	2	9	18
Moderate Slope	East	4	1	1	25	25
Steep Slope	North	11	6	5	55	45
Steep Slope	West	7	1	1	14	14
Moderate Slope	East	6	1	2	17	33
Moderate Slope	East	8	1	0	12	0
Moderate Slope	West	15	0	0	0	0

Moderate Slope	North	14	0	0	0	0
Steep Slope	South	14	0	0	0	0
Steep Slope	West	15	0	1	0	7
Gentle Slope	South	5	0	0	0	0
Moderate Slope	North	13	3	4	23	31
Moderate Slope	East	5	0	1	0	20
Moderate Slope	South	4	1	0	25	0
Moderate Slope	South	6	1	1	17	17
Steep Slope	West	6	2	2	33	33
Steep Slope	North	3	1	1	33	33
Steep Slope	West	17	1	1	6	6
Moderate Slope	West	11	2	1	18	9
Gentle Slope	North	19	2	1	11	5
Moderate Slope	North	10	2	1	20	10
Moderate Slope	South	14	3	3	21	21
Steep Slope	South	6	1	0	17	0
Steep Slope	North	9	1	2	11	22
Steep Slope	North	11	1	1	9	9
Moderate Slope	West	1	1	1	100	100
Moderate Slope	North	2	0	0	0	0
Moderate Slope	East	12	0	0	0	0
Moderate Slope	West	21	0	0	0	0
Moderate Slope	East	18	0	0	0	0
Moderate Slope	North	11	1	0	9	0
Flat Slope	West	17	1	1	6	6
Gentle Slope	North	5	2	2	40	40
Moderate Slope	East	7	2	4	29	57
Moderate Slope	East	6	0	2	0	33
Steep Slope	West	8	0	1	0	12
Steep Slope	West	11	1	0	9	0
Steep Slope	West	14	1	1	7	7
Steep Slope	West	11	1	0	9	0
Moderate Slope	West	13	2	1	15	8
Moderate Slope	West	13	2	2	15	15
Moderate Slope	West	15	1	1	7	7
Steep Slope	South	13	5	2	38	15
Steep Slope	North	2	3	3	150	150
Steep Slope	South	6	1	0	17	0
Moderate Slope	East	16	5	3	31	19
Moderate Slope	East	2	1	0	50	0

Moderate Slope	East	3	0	0	0	0
Steep Slope	North	13	0	0	0	0
Steep Slope	East	12	0	0	0	0
Steep Slope	West	23	0	0	0	0
Gentle Slope	North	8	0	2	0	25
Gentle Slope	East	12	2	1	17	8
Gentle Slope	East	8	2	3	25	38
Moderate Slope	North	4	2	2	50	50
Steep Slope	South	10	0	1	0	10
Steep Slope	South	13	0	1	0	8
Steep Slope	North	14	0	0	0	0
Steep Slope	West	8	1	0	12	0
Steep Slope	West	15	0	0	0	0
Moderate Slope	West	18	1	1	6	6
Moderate Slope	North	11	2	2	18	18
Moderate Slope	North	15	0	1	0	7
Steep Slope	East	18	0	1	0	6
Steep Slope	North	17	0	0	0	0
Steep Slope	South	12	0	3	0	25
Moderate Slope	South	10	1	1	10	10
Moderate Slope	East	14	1	1	7	7
Steep Slope	North	14	2	2	14	14
Steep Slope	West	13	0	0	0	0
Steep Slope	East	10	0	0	0	0
Steep Slope	North	17	0	0	0	0
Gentle Slope	North	9	0	2	0	22
Moderate Slope	East	5	0	1	0	20
Steep Slope	East	13	2	5	15	38
Moderate Slope	East	9	1	0	11	0
Moderate Slope	East	4	1	2	25	50
Steep Slope	North	7	0	2	0	29
Steep Slope	South	4	0	3	0	75
Steep Slope	North	6	0	0	0	0
Steep Slope	South	8	0	0	0	0
Flat Slope	West	13	1	1	8	8
Flat Slope	East	11	0	1	0	9
Moderate Slope	West	8	0	0	0	0
Steep Slope	East	13	2	3	15	23
Moderate Slope	West	18	0	1	0	6
Moderate Slope	East	12	1	2	8	17

Steep Slope	North	15	0	2	0	13
Moderate Slope	North	11	0	1	0	9
Moderate Slope	East	3	0	0	0	0
Steep Slope	East	17	0	0	0	0
Steep Slope	West	19	0	0	0	0
Steep Slope	South	10	0	0	0	0
Gentle Slope	North	9	0	1	0	11
Moderate Slope	South	14	2	1	14	7
Moderate Slope	North	7	2	2	29	29
Moderate Slope	North	9	5	3	56	33
Steep Slope	East	6	1	2	17	33
Steep Slope	South	7	0	0	0	0
Steep Slope	North	4	0	0	0	0
Steep Slope	East	4	2	1	50	25
Steep Slope	South	14	0	1	0	7
Moderate Slope	West	11	0	0	0	0
Moderate Slope	West	14	0	1	0	7
Moderate Slope	North	5	1	2	20	40
Steep Slope	West	14	3	4	21	29
Steep Slope	North	19	0	0	0	0
Moderate Slope	East	8	0	2	0	25
Steep Slope	West	18	0	2	0	11
Moderate Slope	East	13	1	0	8	0
Moderate Slope	West	10	1	0	10	0
Moderate Slope	West	10	2	2	20	20
Moderate Slope	East	10	0	0	0	0
Steep Slope	East	11	0	0	0	0
Gentle Slope	South	5	2	2	40	40
Moderate Slope	North	9	4	3	44	33
Steep Slope	South	11	1	3	9	27
Moderate Slope	South	10	2	4	20	40
Moderate Slope	South	5	0	3	0	60
Steep Slope	South	14	0	2	0	14
Steep Slope	South	11	0	1	0	9
Steep Slope	South	16	0	1	0	6
Steep Slope	North	10	2	2	20	20
Steep Slope	North	17	0	0	0	0
Moderate Slope	South	13	3	2	23	15
Moderate Slope	East	14	1	1	7	7
Steep Slope	South	10	0	1	0	10

Steep Slope	North	1	0	1	0	100
Moderate Slope	West	5	0	0	0	0
Steep Slope	South	23	0	3	0	13
Moderate Slope	North	3	0	0	0	0
Steep Slope	West	15	0	0	0	0
Steep Slope	North	5	0	0	0	0
Steep Slope	North	3	0	0	0	0
Steep Slope	North	1	0	0	0	0
Gentle Slope	West	8	0	0	0	0
Moderate Slope	South	12	3	3	25	25
Moderate Slope	South	15	1	3	7	20
Moderate Slope	West	10	2	3	20	30
Moderate Slope	West	7	1	4	14	57
Moderate Slope	West	12	0	3	0	25
Steep Slope	South	10	1	4	10	40
Steep Slope	East	8	0	1	0	12
Steep Slope	South	10	1	1	10	10
Steep Slope	West	18	3	2	17	11
Moderate Slope	North	13	1	1	8	8
Moderate Slope	West	10	2	1	20	10
Steep Slope	West	14	1	1	7	7
Steep Slope	North	8	2	3	25	38
Moderate Slope	South	5	1	1	20	20
Moderate Slope	North	11	1	0	9	0
Moderate Slope	West	10	2	2	20	20
Moderate Slope	West	11	0	0	0	0
Steep Slope	North	13	0	0	0	0
Steep Slope	North	3	0	0	0	0
Moderate Slope	North	5	0	0	0	0
Gentle Slope	South	9	1	2	11	22
Moderate Slope	West	8	3	2	38	25
Moderate Slope	North	18	1	0	6	0
Moderate Slope	South	13	2	3	15	23
Moderate Slope	North	12	2	1	17	8
Moderate Slope	South	5	0	1	0	20
Steep Slope	South	1	0	0	0	0
Steep Slope	West	2	0	1	0	50
Steep Slope	South	7	0	0	0	0
Steep Slope	West	20	0	1	0	5
Moderate Slope	West	13	0	0	0	0

Moderate Slope	South	9	0	0	0	0
Gentle Slope	North	14	2	2	14	14
Steep Slope	West	10	1	1	10	10
Moderate Slope	South	1	0	0	0	0
Moderate Slope	West	17	1	0	6	0
Moderate Slope	South	2	1	0	50	0
Moderate Slope	South	5	0	0	0	0
Steep Slope	West	14	0	1	0	7
Moderate Slope	East	15	0	0	0	0
Moderate Slope	West	14	0	0	0	0
Moderate Slope	South	3	0	1	0	33
Moderate Slope	South	11	7	4	64	36
Gentle Slope	West	13	4	1	31	8
Moderate Slope	West	17	0	0	0	0
Moderate Slope	East	21	2	2	10	10
Moderate Slope	South	13	0	3	0	23
Moderate Slope	South	16	1	1	6	6
Steep Slope	South	17	0	0	0	0
Steep Slope	South	10	2	1	20	10
Steep Slope	South	19	3	1	16	5
Steep Slope	South	20	0	0	0	0
Moderate Slope	North	6	0	1	0	17
Moderate Slope	North	14	4	4	29	29
Moderate Slope	West	15	3	3	20	20
Gentle Slope	West	16	2	4	12	25
Moderate Slope	East	13	3	3	23	23
Moderate Slope	North	18	0	0	0	0
Moderate Slope	West	11	0	1	0	9
Moderate Slope	North	16	0	0	0	0
Moderate Slope	West	16	0	0	0	0
Moderate Slope	North	8	0	0	0	0
Moderate Slope	East	4	0	1	0	25
Moderate Slope	West	14	2	2	14	14
Moderate Slope	East	11	1	1	9	9
Moderate Slope	North	12	0	0	0	0
Moderate Slope	North	9	1	1	11	11
Steep Slope	North	8	1	2	12	25
Steep Slope	North	12	3	2	25	17
Steep Slope	North	18	1	1	6	6
Steep Slope	South	16	0	0	0	0

Steep Slope	North	18	0	0	0	0
Steep Slope	South	9	0	0	0	0
Moderate Slope	South	11	0	1	0	9
Gentle Slope	West	11	3	2	27	18
Flat Slope	West	12	0	0	0	0
Flat Slope	West	6	3	3	50	50
Moderate Slope	West	12	2	2	17	17
Moderate Slope	North	17	0	1	0	6
Moderate Slope	West	13	0	2	0	15
Steep Slope	South	10	1	1	10	10
Steep Slope	North	10	0	1	0	10
Steep Slope	West	13	2	1	15	8
Gentle Slope	North	14	0	0	0	0
Moderate Slope	South	19	1	2	5	11
Moderate Slope	South	17	0	1	0	6
Moderate Slope	North	16	0	2	0	12
Moderate Slope	West	15	2	1	13	7
Moderate Slope	West	12	1	1	8	8
Moderate Slope	North	14	0	0	0	0
Steep Slope	North	15	4	2	27	13
Steep Slope	South	16	0	0	0	0
Steep Slope	North	13	0	0	0	0
Steep Slope	North	15	0	0	0	0
Steep Slope	North	10	0	0	0	0
Gentle Slope	West	15	1	0	7	0
Flat Slope	West	8	1	0	12	0
Flat Slope	West	8	3	2	38	25
Moderate Slope	West	12	1	1	8	8
Moderate Slope	North	15	0	0	0	0
Moderate Slope	South	12	0	0	0	0
Steep Slope	South	11	1	2	9	18
Steep Slope	North	12	0	0	0	0
Steep Slope	West	14	0	1	0	7
Gentle Slope	North	14	3	2	21	14
Gentle Slope	West	13	4	3	31	23
Gentle Slope	South	13	0	0	0	0
Moderate Slope	North	12	2	2	17	17
Moderate Slope	West	14	1	0	7	0
Moderate Slope	East	14	0	1	0	7
Moderate Slope	South	16	0	0	0	0

Steep Slope	South	18	0	0	0	0
Steep Slope	North	7	0	0	0	0
Steep Slope	South	20	0	0	0	0
Steep Slope	North	21	0	1	0	5
Steep Slope	North	22	0	1	0	5
Gentle Slope	North	23	0	1	0	4
Gentle Slope	East	23	0	1	0	4
Gentle Slope	East	7	0	0	0	0
Moderate Slope	West	18	0	2	0	11
Moderate Slope	North	18	1	1	6	6
Moderate Slope	East	14	0	1	0	7
Steep Slope	North	11	0	1	0	9
Steep Slope	East	9	1	3	11	33
Steep Slope	South	13	0	0	0	0

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