

Fall 2021

## Urban Edge Effects on Soil Conditions, Stand Structure, and Understory Composition in a Coast Redwood Forest

Nanako Oba  
*San Jose State University*

Follow this and additional works at: [https://scholarworks.sjsu.edu/etd\\_theses](https://scholarworks.sjsu.edu/etd_theses)

---

### Recommended Citation

Oba, Nanako, "Urban Edge Effects on Soil Conditions, Stand Structure, and Understory Composition in a Coast Redwood Forest" (2021). *Master's Theses*. 5240.  
DOI: <https://doi.org/10.31979/etd.hqkr-5t5x>  
[https://scholarworks.sjsu.edu/etd\\_theses/5240](https://scholarworks.sjsu.edu/etd_theses/5240)

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact [scholarworks@sjsu.edu](mailto:scholarworks@sjsu.edu).

URBAN EDGE EFFECTS ON SOIL CONDITIONS, STAND STRUCTURE, AND  
UNDERSTORY COMPOSITION IN A COAST REDWOOD FOREST

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Nanako Oba

December 2021

© 2021

Nanako Oba

**ALL RIGHTS RESERVED**

The Designated Thesis Committee Approves the Thesis Titled

URBAN EDGE EFFECTS ON SOIL CONDITIONS, STAND STRUCTURE, AND  
UNDERSTORY COMPOSITION IN A COAST REDWOOD FOREST

by

Nanako Oba

APPROVED FOR THE DEPARTMENT OF ENVIRONMENTAL STUDIES

SAN JOSÉ STATE UNIVERSITY

December 2021

Will Russell, Ph.D.                      Department of Environmental Studies

Rachel O'Malley, Ph.D.                Department of Environmental Studies

Rachel Lazzeri-Aerts, M.S.          Department of Environmental Studies

## ABSTRACT

### URBAN EDGE EFFECTS ON SOIL CONDITIONS, STAND STRUCTURE, AND UNDERSTORY COMPOSITION IN A COAST REDWOOD FOREST

by Nanako Oba

Forests in the wildland-urban interface (WUI) can experience edge effects caused by human activities, such as timber harvest and urban development, altering vegetation composition and structure. Both the WUI and resulting edge effects are well studied in general; however, the influences of the urban edge on coast redwood forests specifically are not well understood. I analyzed soil properties, stand structure, and understory composition in a coast redwood preserve in the Santa Cruz Mountains, California using twenty 300 m transects established across an anthropogenic edge and twenty transects within a forest interior control. Spearman's rank correlations indicated that several variables exhibited positive correlations with distance from the edge, including soil pH and moisture, duff depth, canopy cover, an abundance of *Sequoia sempervirens* and *Notholithocarpus densiflorus*, tree diversity, and the abundance of coast redwood understory species. In contrast, soil temperature and the abundance of *Quercus wislizenii* exhibited negative correlations. Mann-Whitney U and chi-square tests of independence indicated some differences between edge and control treatments with regard to soil conditions, stand structure, and species composition; however, these findings were confounded by unavoidable physiographic and anthropogenic differences between the treatments. The results of this study support previous research in other forest types and provide evidence that urban edges can impact stand structure and understory composition within coast redwood forests.

## ACKNOWLEDGMENTS

I would like to thank many people who gave me so much support throughout my journey as a graduate student. First and foremost, to my thesis chair Dr. Will Russell, thank you for your guidance, support, and extreme patience to make my research possible. To Dr. Rachel O'Malley and Rachel Lazzeri-Aerts, thank you for your valuable advice and wisdom especially during the most challenging times. I was fortunate and grateful to have these three amazing and inspiring committee members.

To my family in Japan, thank you for always being there for me and supporting my dreams. It was sometimes difficult being almost 5,000 miles apart physically especially during the pandemic when the world was in chaos, but I am finally here now thanks to you.

I sincerely appreciate my lovely cohorts and friends for their help. They made my grad school experience vibrant and exciting. Their support means much to me. I owe many thanks to Heidi Giancola and Paul Malonzo for helping me during my data collection and adding joy during the strenuous hike. Thank you to Joia Fishman and Gwen Barry for the tips and tricks on how to drive on the infamous Highway 17. Thank you to Jackie Lee for offering your time checking my thesis and showing enthusiasm and curiosity to my research. To my partner, Nolan, thank you for your unconditional love, countless hours of support during my data collection, and for teaching me how to drive in California to get to my study site safely.

I am thankful for the West San Jose Kiwanis Club, Save-the-Redwoods-League, and SJSU Campus Community Garden for their generous support for making my research happen. I would also like to thank the California State Parks for providing permits and access.

Last but not least, thank you to the coast redwood forest and wildlife for allowing me into their property during my data collection and sharing us your beauty and inspiration every day.

## TABLE OF CONTENTS

List of Tables.....	ix
List of Figures.....	x
Introduction.....	1
Motivation and Scope.....	1
Literature Review.....	2
Wildland-Urban Interface (WUI) Issues.....	2
Edge Effects.....	3
Human-Induced Edge Effects in Forestlands.....	3
Temporary Edges.....	4
Characteristics of Coast Redwood.....	4
Coast Redwood Forest Soil Properties and Edge Effects.....	6
Coast Redwood Forest Composition and Edge Effects.....	7
Problem Statement.....	9
Objective.....	10
Research Questions and Hypothesis.....	10
Methods.....	12
Study Site.....	12
Study Design.....	15
Data Collection.....	18
Data Analysis.....	20
Results.....	22
Soil Properties.....	22
Stand Structure.....	25
Understory Cover and Diversity.....	29
Discussion.....	33
Conclusion.....	37
Recommendations.....	38
Literature Cited.....	39
Appendix A: Mean Stand Density Among Treatments.....	45

Appendix B: Mean Basal Area per Hectare Among Treatments.....	46
Appendix C: Mean Dominance Among Treatments.....	47
Appendix D: Observed Species During Data Collection.....	48

## LIST OF TABLES

Table 1	Soil Compaction Chi-Square Test of Independence Results.....	25
---------	--	----

## LIST OF FIGURES

Figure 1	Study Site Location in Santa Cruz County, California.....	13
Figure 2	Backyard Fences Separating the Residential Area and the Forest of Nisene Marks State Park in the Forest Edge.....	14
Figure 3	Forest Edge and Control Treatments Located in the Southwestern Section of the Forest of Nisene Marks State Park in Aptos, California...	16
Figure 4	A Transect with Ten-Meter Sample Plots with Three One-Meter Diameter Circular Subplots Located in the Forest Edge at the Forest of Nisene Marks State Park, California.....	17
Figure 5	Soil Compaction Tester and the Three Compaction Range Based on the Corresponding Colors.....	19
Figure 6	Mean Soil Temperature in Depth 0-15 and 15-30 cm Among Plot Locations.....	22
Figure 7	Mean Duff Depth Among Plot Locations.....	24
Figure 8	Mean Canopy Cover Among Plot Locations.....	26
Figure 9	Mean <i>Notholithocarpus densiflorus</i> and <i>Quercus wislizeni</i> Stand Density Among Plot Locations.....	27
Figure 10	Mean <i>Oxalis oregana</i> Cover Among Plot Locations.....	30
Figure 11	Mean Non-Native Species Richness Among Plot Locations.....	31
Figure 12	Mean Coast Redwood-Associated Species Richness Among Plot Locations.....	32

## Introduction

### Motivation and Scope

Urbanization is encroaching on forest preserves worldwide, fragmenting and degrading habitat located in the interface between the wildlands and these urban areas (Theobald & Romme, 2007). Within this wildland-urban interface (WUI), edge effects associated with urban development can alter ecological characteristics such as light availability, disturbance regimes, and species composition (Levin et al., 2012; Theobald & Romme, 2007). In forest preserves, these edges may result in forest fragments unable to support the native flora and fauna (Murcia, 1995).

The Santa Cruz Mountains are home to various vegetation types, including coast redwood (*Sequoia sempervirens*) forests, many of which are within the WUI. The WUI commonly fragments coast redwood forests and damages understory-associated plants that are sensitive to disturbance. These plant species include redwood sorrel (*Oxalis oregana*), pacific trillium (*Trillium ovatum*), western sword fern (*Polystichum munitum*), and redwood violet (*Viola sempervirens*) (Hanover & Russell, 2018; Loya & Jules, 2007; Russell, 2020). A better understanding of forest conditions within the WUI will provide vital information for managing coast redwood preserves in urban and exurban areas.

## **Literature Review**

### **Wildland-Urban Interface (WUI) Issues**

Due to significant human population increases and associated development, the area of WUI in the United States has tripled in the past 60 years (Hammer et al., 2009). Future expansion of the WUI will likely exacerbate wildfire issues and increasingly impact natural ecosystems as the human population continues to increase (Hammer et al., 2009). Urban development adjacent to wildlands can introduce non-native species that alter adjacent ecosystems and biodiversity (Buonopane et al., 2013; Radeloff et al., 2018; Theobald & Romme, 2007). In addition, landscapes in the WUI are particularly susceptible to wildfire (Spyratos et al., 2007). Such fires are responsible for 43% of the 3.4 million hectares burned in the U.S. in 2000, resulting in loss of homes and destruction of wildland habitat (Radeloff et al., 2005). In addition, post-fire conditions trigger flood-control problems and damage water quality by releasing toxins into the watershed.

In the western U.S., forestlands are experiencing multiple impacts resulting from urbanization (Buonopane et al., 2013; Radeloff et al., 2005; Theobald & Romme, 2007). Urbanization is responsible for changing and fragmenting the forest environment and risks destroying the quality of ecosystem services (Hull & Nelson, 2011). The WUI is often a mixture of private and public land ownership, low to medium building densities, and roads. The WUI is responsible for increasing solar radiation and air temperature and altering soil properties which may negatively affect the forestlands (Buonopane et al., 2013). The changes in these original environments may ultimately increase invasive species and loss of native species (Buonopane et al., 2013; Radeloff et al., 2018). Also,

the fragmented forests experience widespread wildfires, insect disturbances, and forest diseases (Buonopane et al., 2013). Almost ten percent of the total road length is located within the U.S. national forests in the WUI areas. Roads promote the spread of non-native species into forest ecosystems (Buonopane et al., 2013).

### **Edge Effects**

An edge effect is defined as changes in ecological aspects, such as species richness or population sizes, in the boundary between two ecological communities connected within the same ecosystem (Levin et al., 2012). This phenomenon can have both natural and anthropogenic origins. Natural edge effects often occur on the boundary between two ecosystems, such as the area estuary where saltwater and freshwater combine or transition between a forest and a grassland area. The edge effects associated with urban development can impact ecological characteristics such as light availability, disturbance regimes, and species composition in the boundary between the two adjacent environments (Levin et al., 2012). Anthropogenic edges occur in areas where urban development, logging, road building, or other human activities have altered microclimatic conditions, resulting in changes to soil characteristics, forest composition, and vegetation composition (Dovčiak & Brown, 2014; Halpern & McKenzie, 2001; Hanson & Stuart, 2005).

### **Human-Induced Edge Effects in Forestlands**

Forest edges play an essential role in either natural or managed forestlands, affecting the forest ecosystem and its structure (Esseen et al., 2006). Forest edges can be defined as an interaction between forested and non-forested areas and can be classified into two

groups: natural and anthropogenic edges (Esseen et al., 2006; Hardt et al., 2013; Harper et al., 2005). On the other hand, natural forest edges are created by natural disturbances such as wildfires, windstorms, and natural boundaries between vegetation types (Harper et al., 2015). Anthropogenic edges can trigger critical ecological consequences, such as increasing the chances of harming the edge-sensitive organisms and fragmentation (Didham & Ewers, 2012).

### **Temporary Edges**

Previous studies indicate that temporary edges created by timber harvest affect the structure and composition of vegetation in adjacent old-growth coast redwood forests (Russell & Jones, 2002). Timber harvest creates abrupt changes in light intensity and microclimate within the boundary between timber harvest forests and old-growth forests (Dovčiak & Brown, 2014; Murcia, 1995; Russell & Jones, 2002). Logged edges exhibit distinct microclimatic conditions compared to the forest interior, including higher solar radiation, wind exposure, temperature variation, and soil moisture levels (Dupuch & Fortin, 2013; Malmivaara-Lämsä et al., 2008; Matlack, 1993). Species dependent on old-growth forest environments found in the forest interior are not capable of thriving in the forest edges and tend to be less abundant in the edges (Dupuch & Fortin, 2013). For example, in the coast redwood forest, these species include northern spotted owl, red tree vole, and fisher (Noss, 1999).

### **Characteristics of Coast Redwood**

Coast redwood (*Sequoia sempervirens*) is a long-lived, evergreen tree species native

to the coast of Northern California and Southern Oregon. The name redwood comes from its dark red-brownish bark that is soft, spongy, and fibrous (McBride, 1977). Close relatives are bald cypress (*Taxodium distichum*), giant sequoia (*Sequoiadendron giganteum*), and dawn redwood (*Metasequoia glyptostroboides*). Coast redwood has flat needle-like leaves that grow in a linear form. Cones are small, approximately 2.5 cm long, and are found hanging on the tip of the branches (Lyons & Lazaneo, 2015). It is the tallest tree species on the planet and can grow up to more than 100 meters, with tree diameters up to five meters (Busing & Fujimori, 2002; McBride, 1977; O'Hara et al., 2017; Russell et al., 2019).

Coast redwood grows in a narrow 720 km range distributed from Big Sur, California to Southern Oregon (Barbour et al., 2001; Noss, 1999). Within this region, the coast redwood ecosystem includes approximately 647,000 hectares of land. Of this area, 260,200 hectares are commercial coast redwood timberlands. The remaining area includes parks and mixed forest types that contain coast redwoods. Less than five percent of the original redwood forest exists today (Hanover & Russell, 2018; Russell et al., 2014).

Coast redwoods thrive in a humid region along the Pacific Coast where temperatures are moderate year-round; with warm, wet winters (7°C - 12°C) and cool, dry summers (12°C - 17°C) (Brand & George, 2000). Annual precipitation ranges between 640 and 3,100 mm. This is mainly derived from winter rain; however, snow could cover the area of higher altitude (Olson et al., 1990). The coast redwood's range is likely determined more by the distribution of summer fog rather than the amount of rainfall, as coast

redwoods rely on the presence of coastal fog to capture water resources in the drought months (Johnstone & Dawson, 2010; Olson et al., 1990). Marine fog supports the trees by reducing water loss and provides moisture in the summer season (Olson et al., 1990). Coast redwoods are poor regulators regarding their water usage, highlighting the importance of summer fog as a water source (Johnstone & Dawson, 2010). Although coast redwoods are distributed close to the coast, they cannot tolerate ocean winds as they are sensitive to the salt contained in strong ocean winds (Olson et al., 1990). As a result, coast redwoods are rarely present on hillsides that face the ocean.

Soil conditions can also influence coast redwood growth. Soil pH in the coast redwood forest tends to be slightly acidic and ranges from 5.0 to 6.5 (McBride, 1977; Noss, 1999). Coast redwood trees can grow under various soil moisture patterns; but can only tolerate dry soils for less than 30 days per year (Noss, 1999). In addition, they are not successful in a soil environment that contains excessive amounts of magnesium and sodium (Olson et al., 1990).

### **Coast Redwood Forest Soil Properties and Edge Effects**

Little is known about how urban edge effects influence the soil properties within the coast redwood forests. In general, edge effects can influence soil microbial composition and nutrient flow within the soil, affecting plant diversity and vegetation structure (Malmivaara-Lämsä, 2008). Soil temperature can influence plant growth directly and indirectly and can be affected by induced edges (Paul et al., 2004). Soil pH may affect plant growth as it influences nutrient uptake, root growth, and the activities of microorganisms that exist within the soil. Moreover, studies indicate that the edge effect

can reduce soil and litter (Matlack, 1994). The soil in the coast redwood forest floor is generally covered by a thick layer of duff (decomposing plant material) that creates acidic soil and retains moisture in the soil. The thick duff layer provides conditions to support redwood understory associated species and provides an environment for coast redwood seeds to germinate. Duff is located under the litter (top layer of forest floor, which contains leaves, needles, and fruits) and on top of the mineral soil (National Park Service, 2003). Human activities can cause soil compaction, leading to changes in forest productivity and soil resilience, limiting air and water transportation within the soil, resulting in oxygen deficiency (Hwang et al., 2020; McBride, 1977). Forests near urban areas tend to have higher foot traffic and a greater degree of road construction which can cause soil compaction and affect forest productivity and soil resilience (Hwang et al., 2020).

### **Coast Redwood Forest Composition and Edge Effects**

Forest fragmentation is closely associated with the edge effect phenomena. It reduces the total area of the original forestland and exposes organisms to a completely different environment (Murcia, 1995). The edge heavily influences the composition and abundance of organisms within forest fragments (Didham & Ewers, 2012). Edge effects are particularly problematic for coast redwood understory species, such as redwood sorrel (*Oxalis oregana*), wild ginger (*Asarum caudatum*), western wake robin (*Trillium ovatum*), California huckleberry (*Vaccinium ovatum*), and Western sword fern (*Polystichum munitum*); as they are adapted to a cool and moist forest floor, are shade

tolerant, and are generally sensitive to human disturbance (Hanover & Russell, 2018; Lyons & Lazaneo, 2015; Olson et al., 1990; Russell, 2020).

Anthropogenic edges can be following temporary disturbances such as logging or permanent with the construction of roads and housing developments. Permanent edges create an enduring area of transition between microclimates, including gradients of light intensity, wind exposure, humidity, and temperature (Gascon et al., 2000; Matlack, 1994). These gradients can be severe, especially in urban areas where the modified nutrient flow can affect forest ecosystems over the long term (Christie & Hochuli, 2005; Hamberg et al., 2009). As a result, permanent edges have a significant influence on tree mortality, composition and abundance of plant species, forest structure, leaf fall, distribution of animals, and seed dispersion within the edge environment (Gascon et al., 2000; Hamberg et al., 2008, 2009; Malmivaara-Lämsä et al., 2008; Matlack, 1994).

## Problem Statement

Forests provide essential environmental services, including watersheds, carbon sequestration, and habitat for various terrestrial and aquatic species. Coast redwood forests, home to California's iconic tree species *Sequoia sempervirens*, are particularly effective in this regard, elevating the summer water budget through fog capture; providing the highest level of carbon storage of any terrestrial ecosystem on earth; providing habitat for several threatened wildlife species; and providing the canopy conditions necessary for shade-dependent understory species. Species such as western wake robin (*Trillium ovatum*), redwood sorrel (*Oxalis oregana*), and pacific starflower (*Trientalis latifolia*) rely on the presence of coast redwood forests and are indicators of forest health following human disturbance (Lyons & Lazaneo, 2015; Russell, 2020). The Santa Cruz Mountains contain a mosaic of old-growth and second-growth coast redwood within a matrix of urban and exurban development.

Edges can affect physical parameters such as sunlight, wind, and moisture. Furthermore, edges can influence individual species diversity and population size in the boundary between two ecological communities (Levin et al., 2012). However, particularly regarding soil properties, forest composition, and understory species. A better understanding of the WUI and its effects on the coast redwood forest will provide essential information for managing this forest type within the WUI.

## **Objective**

The objective of this study was to examine how urban edges influence soil properties, forest structure, and understory species composition within the WUI in the Forest of Nisene Marks State Park coast redwood preserve in the Santa Cruz Mountains, California.

## **Research Questions and Hypothesis**

RQ1a: Are soil properties (temperature, pH, moisture, depth duff, and compaction) associated with distance from permanent induced edges at the Forest of Nisene Marks State Park?

H01a: Soil properties do not correlate with distance from permanent induced edges at the Forest of Nisene Marks State Park.

RQ1b: Does the forest edge differ from the control site in terms of soil properties?

H01b: Soil properties do not differ between the forest edge and the control site.

RQ2a: Are stand structure metrics (canopy cover, stand density, basal area, dominance, and tree species diversity) associated with distance from permanent induced edges within the Forest of Nisene Marks State Park?

H02a: Stand structure metrics do not correlate with distance from permanent induced edges at the Forest of Nisene Marks State Park.

RQ2b: Does the forest edge differ from the control site in terms of stand structure?

H02b: Stand structure metrics do not differ between the forest edge and the control site.

RQ3a: Is understory species composition associated with distance from permanent induced edges within the Forest of Nisene Marks State Park?

H03a: Understory composition does not correlate with distance from permanent induced edges at the Forest of Nisene Marks State Park.

RQ3b: Does the forest edge differ from the control site in terms of understory composition?

H03b: Understory composition does not differ between the forest edge and the control site.

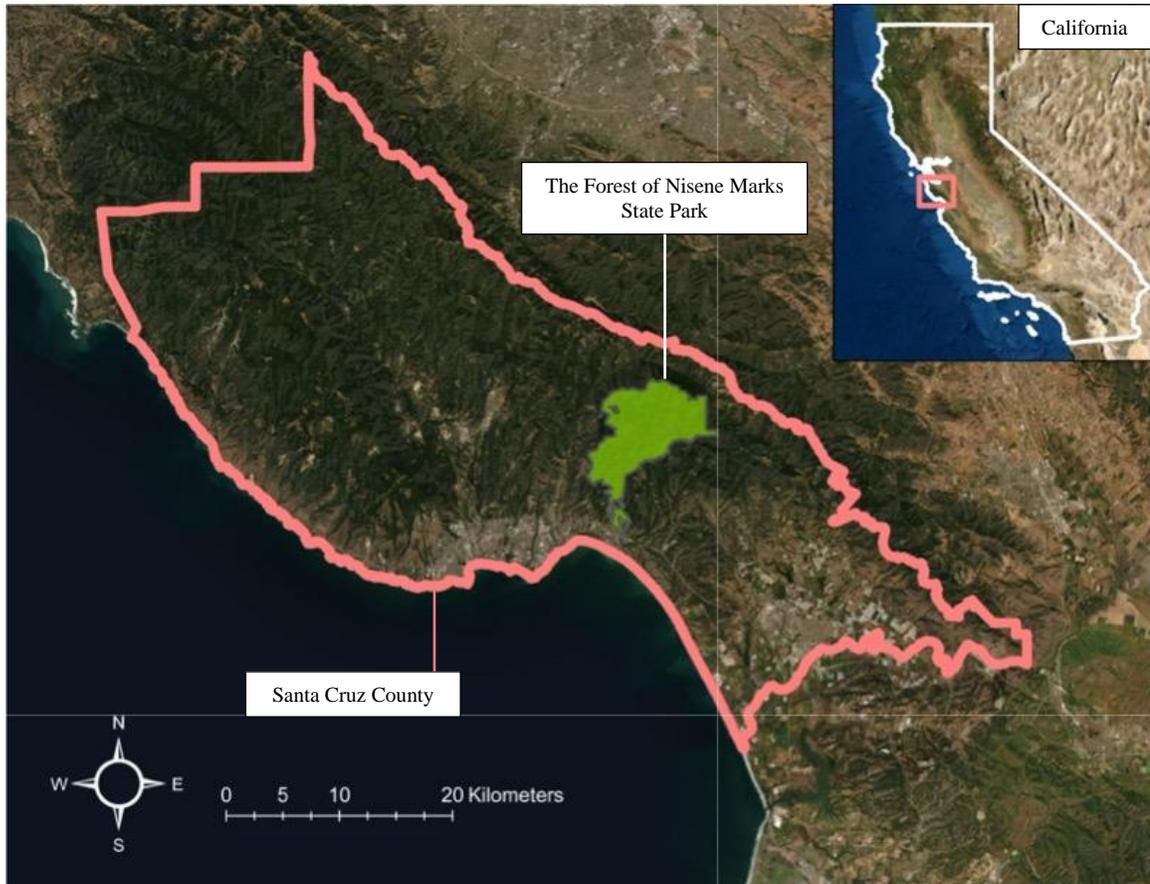
## Methods

### Study Site

Data was collected in the Forest of Nisene Marks State Park (37.0175° N - 121.9053° W) in the Santa Cruz Mountains, California, adjacent to an urban area (Figure 1). The Santa Cruz Mountains are approximately 120 km south of San Francisco and are located in the northern Monterey Bay region. The area experiences a Mediterranean climate with dry cool summers, and wet moderate winters. The average summer temperature is 20°C and the winter temperature is 10°C (Stephens & Fry, 2005). Annual rainfall ranges from 70 to 200 cm and 72% of rainfall occurs during the winter season (Anderson, 1994; Stephens & Fry, 2005). Vegetation in the Santa Cruz Mountains is a mosaic of coast redwood stands, mixed evergreen forests with Douglas-fir (*Pseudotsuga menziesii*) and tanoak (*Notholithocarpus densiflorus*) dominant, oak woodland, grassland, chaparral, and coastal scrub (Russell et al., 2014). Coast redwoods are generally found on the west, and ocean-facing, aspects of the mountains. The soil in the region consists primarily of marine sediments and sandstone with rich nutrients and mildly acidic to alkaline pH levels (Russell et al., 2014).

**Figure 1**

*Study Site Location in Santa Cruz County, California*



The Forest of Nisene Marks State Park is located in Aptos, an unincorporated town in Santa Cruz County, with an elevation ranging from sea level to 790 m (California Department of Parks and Recreation, 2018). Aptos holds 24,402 people with 21,000 settled in the urban area, such as the Cabrillo area, Seacliff, Rio Del Mar, and Seascape. According to the 2010 United States Census Bureau, the population density in Aptos was 378.0 people per square kilometer (United States Census Bureau, 2010).

The total length of forest edge within the State Park adjacent to residential urban

development is 2,830 m. The residential area and the State Park were separated with backyard fences (Figure 2). In this 4,100 ha park, eighty percent of the area is dominated by coast redwood, with a few residual old-growth coast redwoods existing within the park (California Department of Parks and Recreation, 2018). The remaining area comprises five percent of northern maritime chaparral dominated by coyote bush (*Baccharis pilularis*) and woolly leaf manzanita (*Arctostaphylos tomentosa*). The remaining habitats include grassland that contains purple needlegrass (*Nassella pulchra*) and red alder (*Alnus rubra*) woodlands. The diverse environment within the park provides habitats for wildlife, including deer, cougar, saw-whet owl, and banana slugs (California Department of Parks and Recreation, 2018).

**Figure 2**

*Backyard Fences Separating the Residential Area and the Forest of Nisene Marks State Park in the Forest Edge*



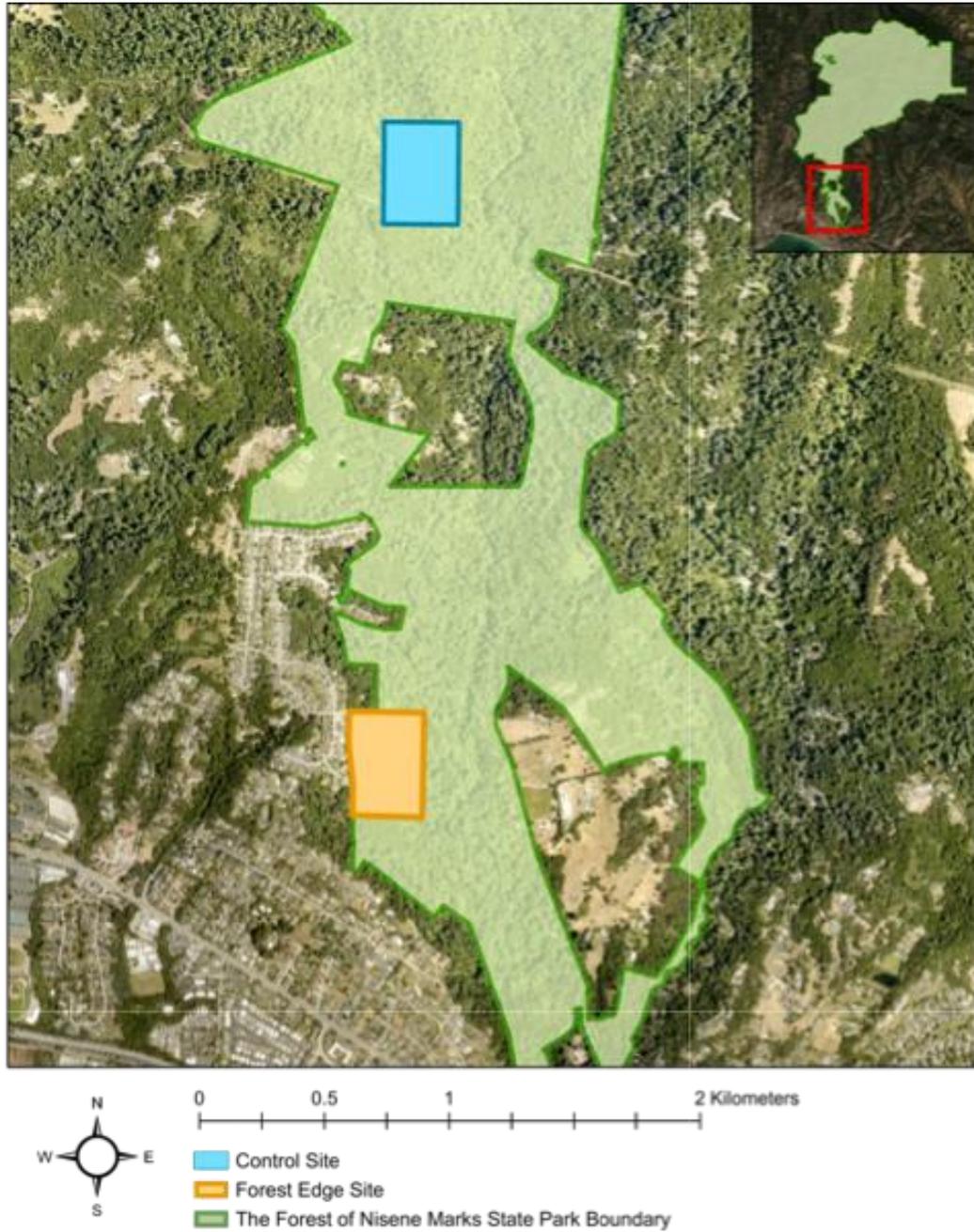
The Awaswas people (Santa Cruz Costanoan) first occupied the land and harvested resources in the coast redwood forest edges. Little is known about the indigenous uses of resources deeper in the forest (California Department of Parks and Recreation, 2018; Campbell, 2000). The area experienced forty years of high-intensity logging (1883–1923) by the Loma Prieta Lumber Company (California Department of Parks and Recreation, 2018). During the logging period, the area was replanted with invasive eucalyptus seedlings, covering nearly 20 ha of the area. After the Loma Prieta mill was abandoned, the land was gifted to the State of California. Eventually, with the help of donations, the state park was expanded to 4,100 ha (California Department of Parks and Recreation, 2018).

### **Study Design**

Within the study area, forty 300 m transects were established. Out of these, twenty transects were located along the forest edge (Figure 3). These forest edge transects were placed randomly along the 400 m urban edges in the southwestern section of the State Park using a random number generator. The urban edge was defined as anthropogenic permanent edges at the external boundaries of the preserve created by residential urban development. The remaining twenty transects were installed as controls in an interior section of the forest with similar aspect and elevation as the edge transects (Figure 3). Controls were placed a minimum of 300 m away from the urban edges, as literature indicates that edge effects range between 20 to 300 meters (Hardt et al., 2013). The minimum and maximum distances between transects were 1 m and 64 m, respectively.

**Figure 3**

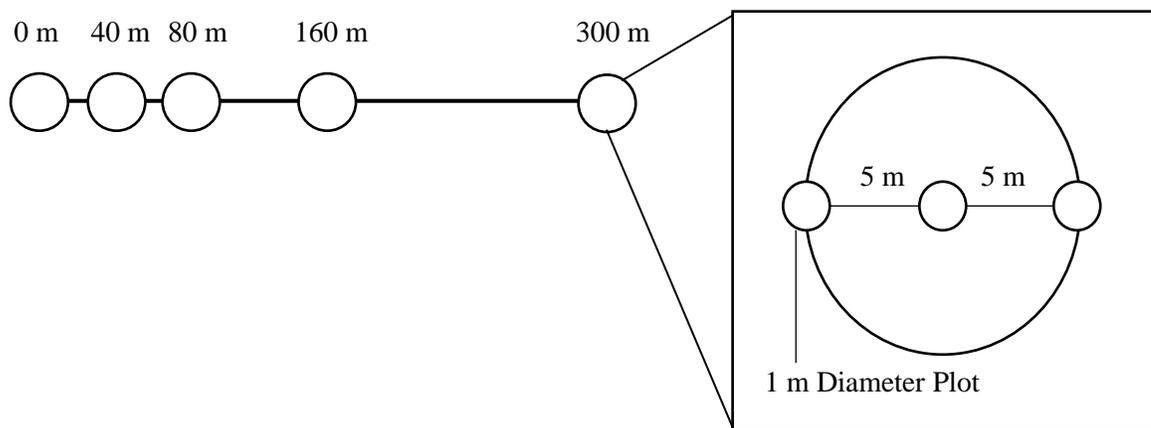
*Forest Edge and Control Treatments Located in the Southwestern Section of the Forest of Nisene Marks State Park in Aptos, California*



Five circular ten-meter diameter plots were sampled within each transect, resulting in a total of 200 plots. Plots were distributed exponentially (0, 40, 80, 160, and 300 m starting from the forest edge) rather than having equal distances between plots. These plot distributions were an accepted and efficient method to reach the forest interior (Sampaio & Scariot, 2011). The 0 m plots were placed within ten meters from the boundary. These ten-meter diameter sample plot locations were established using Google Earth Pro, and the Gaia GPS Hiking Offroad Maps app was used to locate the sample plots in the field. Within each ten-meter diameter sample plot, three one-meter diameter circular subplots were nested along the transect (Figure 4). Subplots were established in the center and each side of the sample plots and were utilized to estimate understory species cover, richness, evenness, and diversity (Hanover & Russell, 2018; Russell et al., 2014).

**Figure 4**

*A Transect with Ten-Meter Sample Plots with Three One-Meter Diameter Circular Subplots Located in the Forest Edge at the Forest of Nisene Marks State Park, California*



## **Data Collection**

Within each sample plot, the following variables were recorded: (1) soil properties, (2) stand structure, and (3) understory species composition. Slope and aspect were recorded using the iHandy Level app and a compass app respectively at the center of each sample plot.

Soil properties characterized each sample plot included soil temperature, pH, moisture, duff depth, and compaction. At the beginning and the end of field sampling, ambient air temperature and moisture were recorded using a Digital Psychrometer Thermo-Hygrometer Preciva©. Soil temperature data was measured using Luster Leaf© 1618 Rapitest Soil Thermometer within the sample plots in the depth of 0-15 cm and 15-30 cm after removing the natural mulch (Shreve, 1927). Kelway© Soil pH and Moisture Meter was used within the sample plots to measure soil pH and moisture. Soil pH and moisture measurements were conducted at depths of 0-15 cm and 15-30 cm after removing the mulch (Lebron et al., 2012). When the soil was too dry to measure soil pH, distilled water was added to the soil to record the proper pH. A shovel was inserted into the ground until it hit the mineral soil at each sampling point to measure duff depth. After removing the natural mulch carefully to expose both litter and duff, duff depth was measured vertically using a metric ruler (National Park Service, 2003). Soil compaction was measured using the Dicky-John© Soil Compaction Tester within the sample plots after removing the natural mulch (Agarwala et al., 2017). The soil compaction range was classified into three categories based on the soil compaction tester used for this research (Figure 5).

**Figure 5**

*Soil Compaction Tester and the Three Compaction Range Based on the Corresponding Colors*



Color	Compaction	Description
Green	0-200 psi	plants grow well
Yellow	200-300 psi	plants grow fair
Red	over 300 psi	plants grow poor

Canopy cover was measured using a Forestry Suppliers© Spherical Crown Densiometer, Convex Model A (Hageseth, 2008; Hanover & Russell, 2018). Stand density was determined by counting the total number of trees taller than one meter within the sample plot. Diameter at breast height (DBH) of each tree taller than one meter in height and over ten centimeters DBH was measured using a 10-meter Forestry Suppliers© Metric Diameter Tape to estimate basal area (defined as the area that is occupied by each tree). Furthermore, basal area was used to calculate the relative dominance of each tree species (Hageseth, 2008). Trees were recorded if at least fifty percent of the trunk were in the sample plot boundaries (Hanover & Russell, 2018). Trees with multiple trunks were recorded as individual trees if the separation was located below

1.37 meters. Trees that were less than one meter in height were recorded as seedlings (Hageseth, 2008).

All shrub and herbaceous species under five meters in height were recorded within each subplot, and ocular cover estimates were made (Hanover & Russell, 2018). Species were identified using the Jepson Manual and categorized as non-native, native, and redwood-associated species (Baldwin et al., 2012). Data from subplots were also used to determine species richness (the number of species per unit area), an essential metric when assessing ecosystem diversity (Magurran & McGill, 2011). Species evenness (distribution of abundance in an area) was calculated by using Pielou's evenness index. Shannon Diversity Index was used to estimate species diversity (Hageseth, 2008).

### **Data Analysis**

IBM SPSS Statistics version 25 was used to conduct a two-sample t-test, Mann-Whitney U test, chi-square test of independence, and Spearman's rank correlation. For all tests, the significance level was set at  $\alpha = .05$ .

RQ1, RQ2, and RQ3: Two-sample t-test and Mann-Whitney U test were used to determine differences between the forest edge and control treatment for the variables, including soil properties, stand structure, and understory species composition. Spearman's rank correlation was selected to explore the relationship between the variables except for soil compaction and the distance from the edges within the two treatments.

RQ1: For soil compaction, a chi-square test of independence test was used to evaluate

the relationship between the forest edge and the control site. A chi-square test was chosen for soil compaction analysis since it was used to determine if two categorical variables (soil compaction and distance from edge) had a significant difference. A two by two chi-square test was used to avoid type two errors.

## Results

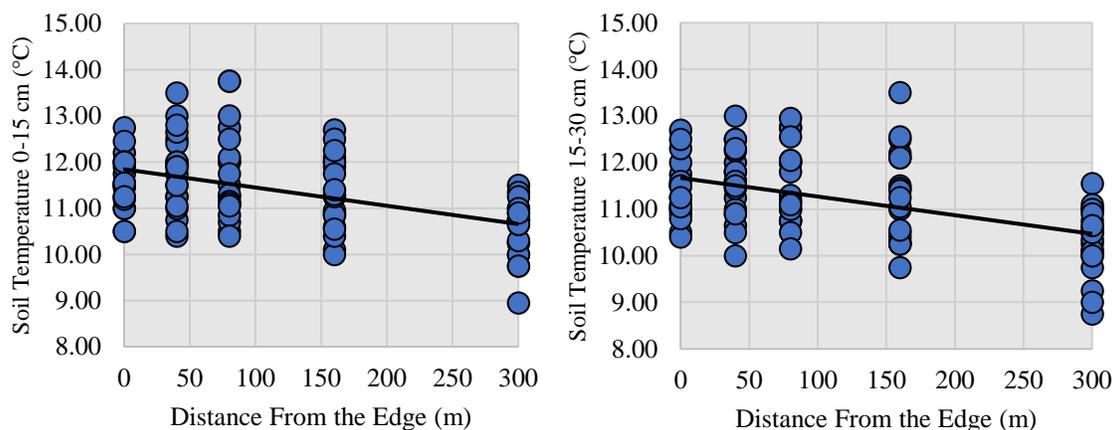
Variation was found between treatments (edge and control) and distance from the edge for physical soil parameters, stand structure, and understory composition. There was a distinct difference between the two treatments, edge and control. There were correlations with many of the variables with distance from the edge in the edge treatment.

### Soil Properties

Soil temperature, pH, moisture, soil compaction, and duff depth varied between samples. While there was a strong negative correlation between distance from the edge and the soil temperature for soil depths of both 0-15 cm [ $r(198) = -.43, p < .001$ ; Figure 6] and 15-30 cm [ $r(198) = -.41, p < .001$ ; Figure 6]. There was no significant difference detected in soil temperature between the forest edge and control sites in both shallow (U = 4,567,  $p = .290$ ) and deep sections (U = 4,828,  $p = .673$ ).

**Figure 6**

*Mean Soil Temperature in Depth 0-15 and 15-30 cm Among Plot Locations*

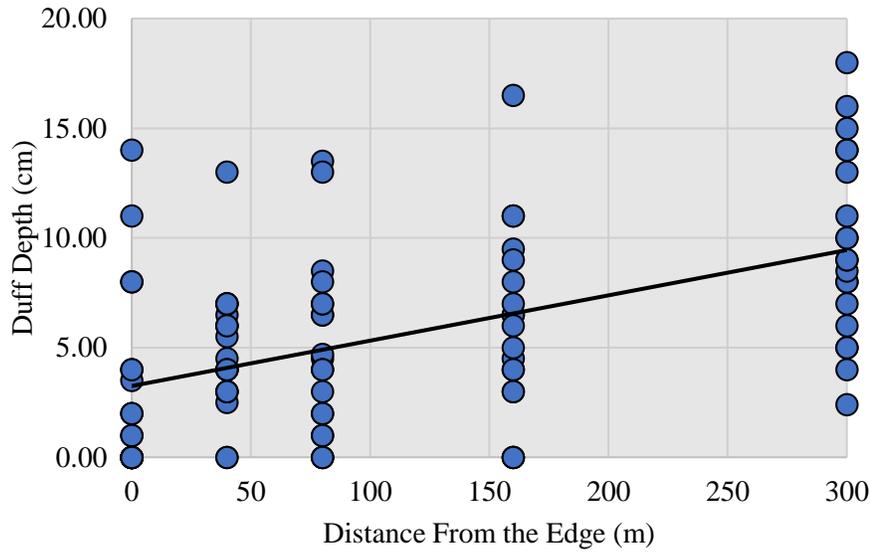


*Note.* Mean soil temperature in depth 0-15 and 15-30 cm among plots (0, 40, 80, 160, 300 m) in the Forest of Nisene Marks State Park forest edge treatment.

There was very little relationship between distance from the edge and soil pH, with only a weak positive relationship for the 0-15 cm depth [ $r(198) = .25, p = .011$ ]. No correlation was noted for depth 15-30 cm [ $r(198) = .18, p = .076$ ]. No difference in pH was noted between the forest edge and control treatment in both shallow ( $U = 4,884, p = .776$ ) and deep sections ( $U = 4,279, p = .078$ ). In contrast, there was a moderate positive relationship between soil moisture and distance from the edge at soil depth 15-30 cm [ $r(198) = .32, p = .001$ ], but no correlation was found at a depth of 0-15 cm [ $r(198) = .08, p = .418$ ]. In addition, soil moisture in the control treatment was statistically higher than the forest edge treatment for both shallow ( $U = 2,736, p < .001$ ) and deep sections ( $U = 2,570, p < .001$ ). Duff depth had a strong positive relationship between the distance from the edge [ $r(98) = .48, p < .001$ ; Figure 7]. Furthermore, duff depth in the forest edge was statistically higher than the control site ( $U = 3,288, p < .001$ ).

**Figure 7**

*Mean Duff Depth Among Plot Locations*



*Note.* Mean duff depth among plots (0, 40, 80, 160, 300 m) in the Forest of Nisene Marks State Park forest edge treatment.

A chi-square test of independence illustrated that the proportion of samples experiencing compaction over 200 psi was greater near the forest edge [ $\chi^2(1) = 4.68, p = .031$ ; Table 1]. The analysis showed no difference in soil compaction between the edge and the control treatments [ $\chi^2(1) = .05, p = .826$ ].

**Table 1***Soil Compaction Chi-Square Test of Independence Results*

Soil Compaction	Distance from edge of plot	
	40 m and under	80 m and over
Under 200 psi	50 (62%)	92 (77%)
Over 200 psi	30 (38%)*	28 (23%)
Total	80	120

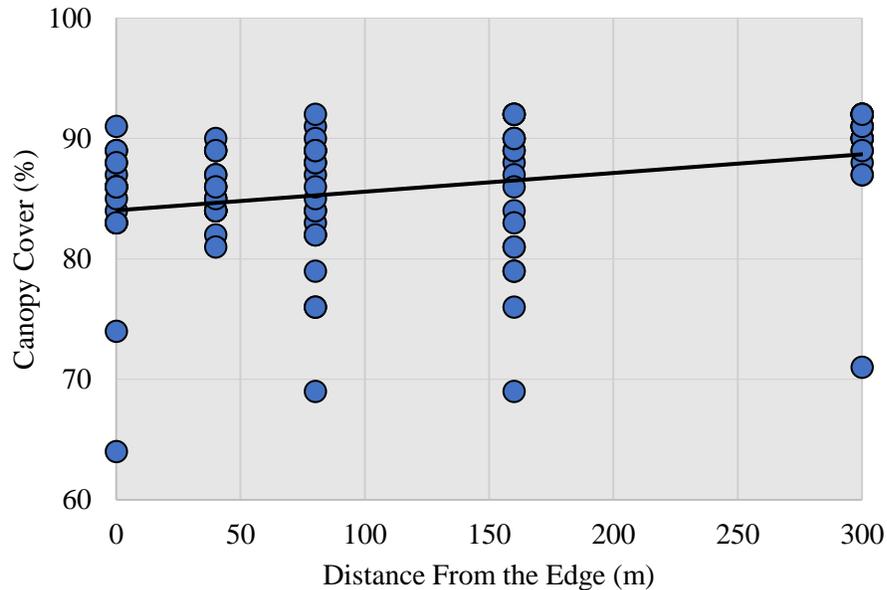
*Note.* \* indicates statistical significance. Chi-square test of independence significance level was set at  $\alpha = .05$ .

**Stand Structure**

Variation in forest canopy cover was detected between and within treatments. A Spearman's rank correlation test indicated a strong positive relationship between distance from the edge and canopy cover [ $r(98) = .40, p < .001$ ; Figure 8]. In addition, canopy cover in the control site was statistically higher than the forest edge site, based on a Mann-Whitney U test ( $U = 3,466, p < .001$ ).

**Figure 8**

*Mean Canopy Cover Among Plot Locations*



*Note.* Mean canopy cover among plots (0, 40, 80, 160, 300 m) in the Forest of Nisene Marks State Park forest edge treatment.

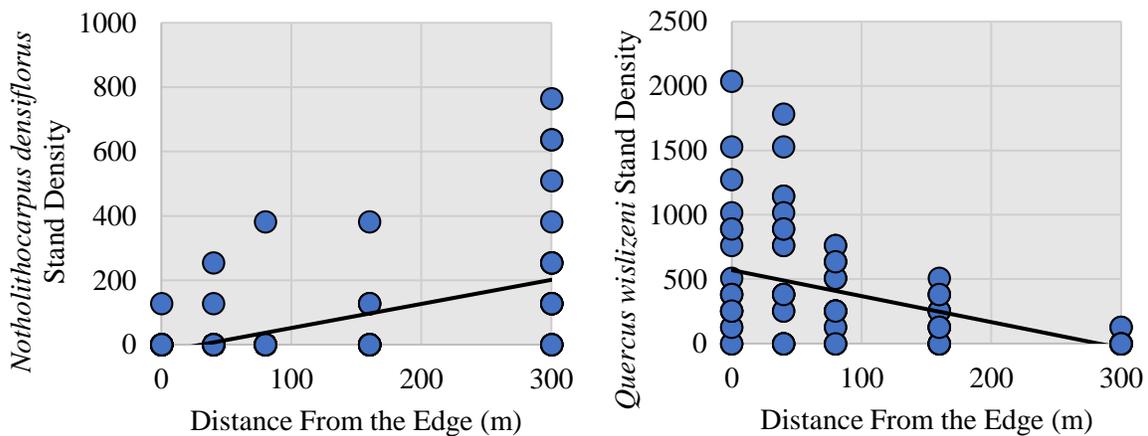
A total of eight tree species were recorded in the study site, including coast redwood (*Sequoia sempervirens*), tanoak (*Notholithocarpus densiflorus*), Pacific madrone (*Arbutus menzessii*), interior live oak (*Quercus wislizeni*), Douglas-fir (*Pseudotsuga menziesii*), big leaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), and California laurel (*Unbellularia californica*). No correlation was detected between the distance from the edge and stand density [ $r(98) = -.17, p = .880$ ], but the forest edge site had a greater total stand density compared to the control site ( $U = 3,961, p = .010$ ).

Mean stand density for eight tree species were calculated (Appendix A). The highest densities were found for *Sequoia sempervirens*, *Notholithocarpus densiflorus*, and *Quercus wislizeni*. Individual analysis for these three species indicated that a positive

correlation was found between distance from the edge and stand density for *Sequoia sempervirens* [ $r(98) = .28, p = .005$ ] and *Notholithocarpus densiflorus* [ $r(98) = .51, p < .001$ ; Figure 9], while a negative correlation was found for *Quercus wislizeni* [ $r(98) = -.56, p < .001$ ; Figure 9]. In addition, there was no difference in *Sequoia sempervirens* ( $U = 4,991, p = .978$ ) and *Notholithocarpus densiflorus* stand density ( $U = 5,573, p = .078$ ) between treatments. However, *Quercus wislizeni* stand density was greater in the forest edge compared to the control treatment ( $U = 3,829, p = .003$ ).

**Figure 9**

*Mean Notholithocarpus densiflorus and Quercus wislizeni Stand Density Among Plot Locations*



*Note.* Mean *Notholithocarpus densiflorus* and *Quercus wislizeni* stand density among plots (0, 40, 80, 160, 300 m) in the Forest of Nisene Marks State Park forest edge treatment.

Mean basal area per hectare among study area for all eight tree species were recorded (Appendix B). No relationship was detected between the distance from the edge and the overall basal area [ $r(98) = .12, p = .236$ ]. However, the total basal area was higher in the forest edge than the control treatment, based on a Mann-Whitney U test ( $U = 4,072, p$

= .023). Individual analysis was done for the top three species: *Sequoia Sempervirens*, *Notholithocarpus densiflorus*, and *Quercus wislizeni*. There was a weak positive correlation between the distance from the edge and *Sequoia sempervirens* basal area [ $r(98) = .27, p = .006$ ]. There was a moderate negative relationship noted for *Quercus wislizeni* basal area [ $r(98) = -.38, p < .001$ ]. However, there was no statistical difference in *Sequoia sempervirens* ( $U = 4,912, p = .774$ ), *Notholithocarpus densiflorus* ( $U = 4,598, p = .226$ ), and *Quercus wislizeni* basal area ( $U = 4,469, p = .159$ ) between the forest edge and control site.

Mean dominance among study area for all eight tree species were measured (Appendix C). Individual analysis was conducted with regard to dominance for the three most common tree species; *Sequoia sempervirens*, *Notholithocarpus densiflorus*, and *Quercus wislizeni*. There was a weak positive relationship between the distance from the edge and *Sequoia sempervirens* dominance [ $r(98) = .25, p = .011$ ], a strong positive relationship for *Notholithocarpus densiflorus* [ $r(98) = .53, p < .001$ ], and a strong negative relationship for *Quercus wislizeni* dominance [ $r(98) = -.50, p < .001$ ]. However, there was no difference in *Sequoia sempervirens* ( $U = 4,974, p = .932$ ), *Notholithocarpus densiflorus* ( $U = 4,525, p = .137$ ), and *Quercus wislizeni* dominance ( $U = 4,277, p = .056$ ) between the forest edge and the control site.

The richness of tree species had a positive relationship between distance from the edge [ $r(98) = .24, p = .015$ ], and the tree species richness was statistically higher in the forest edge site compared to the control site ( $U = 3,661, p < .001$ ). In addition, no correlation was found between distance from the edge and tree species evenness [ $r(98)$

= .22,  $p = .031$ ], but was statistically higher in the forest edge site than the control site ( $U = 3,815, p = .032$ ). For tree species diversity, a Spearman's rank correlation test illustrated that there was no relationship between the distance from the edge and species diversity for tree species [ $r(98) = .17, p = .086$ ], and the forest edge site was statistically higher than the control site ( $U = 3,664, p = .010$ ).

### **Understory Cover and Diversity**

No correlation between overall understory cover and distance was detected based on Spearman's rank correlation [ $r(98) = .11, p = .272$ ]. However, the total cover of understory species varied between treatments, with significantly higher cover recorded in the forest edge than the control treatment ( $U = 3,489, p < .001$ ).

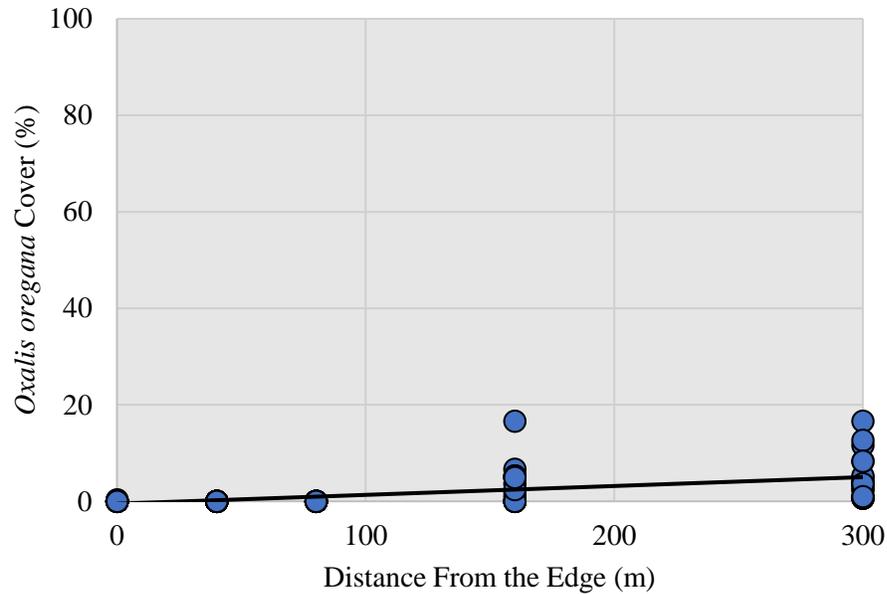
A total of thirty-seven native understory species including, *Adelina grande* (pacific hound's tongue), *Artemisia douglasiana* (California mugwort), and *Fragaria vesca* (wild strawberry), were recorded in the treatment areas (Appendix D). There was no relationship between the plot location and the mean native understory species cover [ $r(98) = .19, p = .063$ ]. Native understory species cover was significantly higher in the forest edge compared to the control treatment ( $U = 3,092, p < .001$ ). Furthermore, no correlation was found between plot location and the mean native species richness [ $r(98) = .19, p = .060$ ] and was statistically higher in the forest edge compared to the control site ( $U = 3,987, p = .012$ ).

*Oxalis oregana*, redwood sorrel, was selected as a redwood-associated species indicator for individual analysis as it was observed commonly throughout the study area. A Spearman's rank correlation indicated that there was a positive relationship between

plot location and the mean *Oxalis oregana* cover [ $r(98) = .74, p < .001$ ; Figure 10], while no difference was found between the treatments ( $U = 4,359, p = .311$ ).

**Figure 10**

*Mean Oxalis oregana Cover Among Plot Locations*



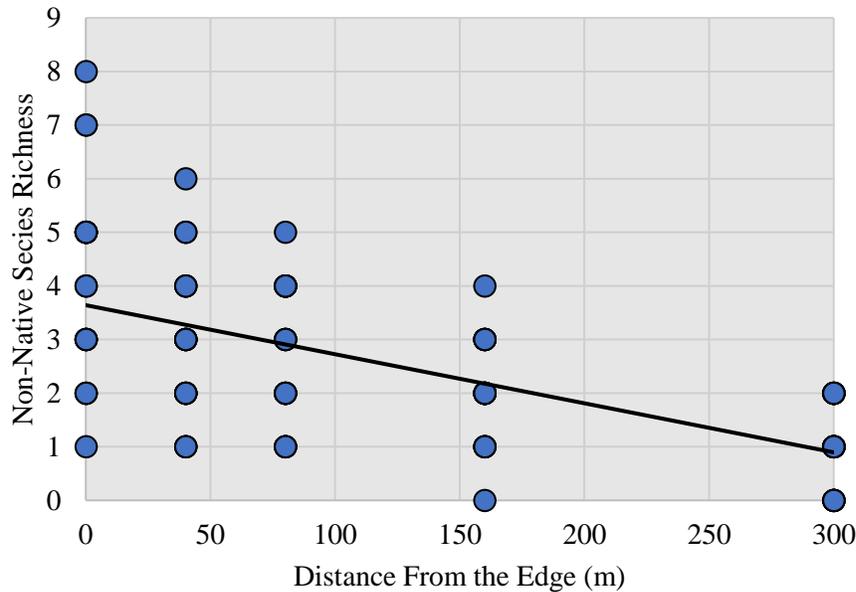
*Note.* Mean *Oxalis oregana* cover among plots (0, 40, 80, 160, 300 m) in the Forest of Nisene Marks State Park forest edge treatment.

At the study site, a total of thirteen non-native species were observed, with five species recorded within the control treatment and eleven species recorded within the edge treatment (Appendix D). There was a negative correlation between distance from the edge and the non-native understory species cover for the forest edge site [ $r(98) = -.38, p < .001$ ]. The non-native understory species cover in the control site was statistically higher than the forest edge site ( $U = 3,832, p = .019$ ). Furthermore, there was a negative correlation between distance from the edge and non-native species richness in the forest

edge treatment [ $r(98) = -.61, p < .001$ ; Figure 11]. Non-native species richness was statistically higher in the forest edge compared to the control site ( $U = 2,068, p < .001$ ).

**Figure 11**

*Mean Non-Native Species Richness Among Plot Locations*

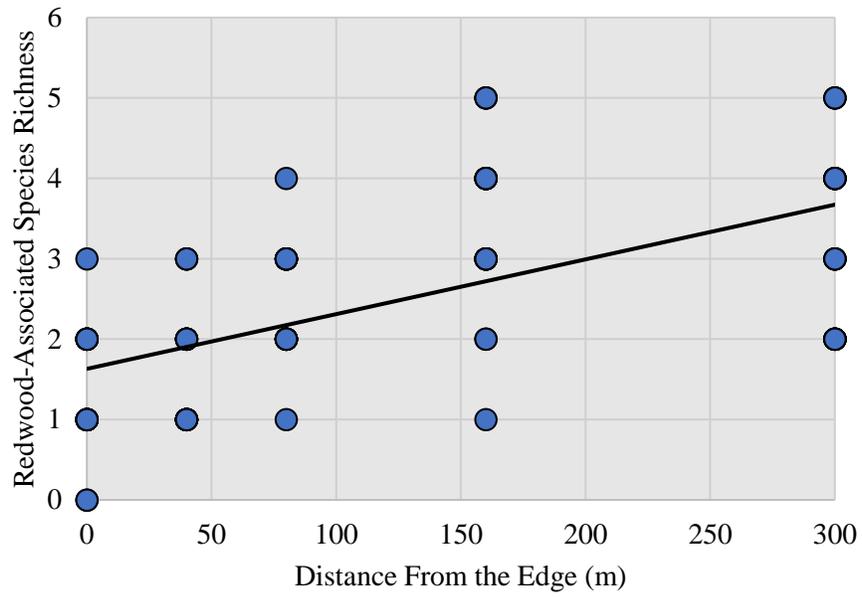


*Note.* Mean non-native species richness among plots (0, 40, 80, 160, 300 m) in the Forest of Nisene Marks State Park forest edge treatment.

A total of thirteen coast redwood understory species were found (Appendix D), with a weak positive relationship between plot location and the mean coast redwood understory species cover [ $r(98) = .23, p = .036$ ]. Coast redwood-associated understory species cover in the forest edge site was statistically higher than the control site ( $U = 2,837, p = .001$ ). There was a strong positive correlation between the distance from the edge and the coast redwood-associated species richness [ $r(98) = .67, p < .001$ ; Figure 12]. Moreover, the forest edge site was statistically higher than the control site ( $U = 4,168, p = .034$ ).

**Figure 12**

*Mean Coast Redwood-Associated Species Richness Among Plot Locations*



*Note.* Mean coast redwood-associated species richness among plots (0, 40, 80, 160, 300 m) in the Forest of Nisene Marks State Park forest edge treatment.

## Discussion

The results of data collected in the Forest of Nisene Marks State Park indicate that several variables were correlated with the distance from the edge. Soil pH, soil moisture (15-30 cm), duff depth, canopy cover, *Sequoia sempervirens* stand density, *Notholithocarpus densiflorus* stand density, *Sequoia sempervirens* basal area, *Sequoia sempervirens* dominance, *Notholithocarpus densiflorus* dominance, tree species richness, evenness, coast redwood understory species cover, *Oxalis oregana* cover, and coast redwood understory species richness exhibited a positive correlation. In addition, soil temperature, *Quercus wislizeni* stand density, basal area, and dominance had a negative correlation.

Furthermore, findings indicated some differences between the forest edge and control treatments regarding some of the measured variables. Variables include duff depth, total stand density, total basal area, *Quercus wislizeni* stand density, *Notholithocarpus densiflorus* dominance, tree species richness, evenness, diversity, total understory species cover, native understory species cover and richness, and coast redwood associated understory species cover and richness were higher in the forest edge treatment. Meanwhile, soil moisture, canopy cover, and non-native species richness were higher in the control treatment. These results were not as clear as those found for the distance from the edge analysis, as the control site has several unavoidable differences from the edge site regarding trail network, logging history caused by the Loma Prieta Lumber Company, and tree canopy openings caused by power lines. In addition, lack of both

forest edge and control treatments placements may contributed to the unclear results in the pairwise comparison.

While there was a strong negative relationship between distance from the edge, there was no significant difference in soil temperature between the forest edge and control treatment. Earlier studies have shown that forest edges tend to have an environment of lower humidity and higher air temperatures which causes an increase in soil temperature (de Casenave et al., 1995; Jose et al., 1996; Kapos, 1989). In this case, the gradual soil temperature changes from the edge may be associated with the edge effect. Soil pH (0-15 cm) showed a weak positive correlation in the forest edge site. Lower soil pH at the edges may be caused by runoffs from landscapes and backyard gardens located near the edge. However, changes in soil pH can also be affected by tree litter which in this study, a strong positive correlation was found for duff depth in the forest edge (Malmivaara-Lämsä et al., 2008). Soil moisture in the control treatment was statistically greater than the forest edge treatment. Supporting research indicates that reduced canopy cover derived from forest fragmentations can result in increased solar radiation and wind exposure causing higher evaporation rates and reduced moisture content in soil and litter (Camargo & Kapos, 1995; Matlack, 1994; Riutta et al., 2012).

As predicted, canopy cover had a strong positive relationship between distance from the edge. In addition, the cover was higher in the control site compared to the edge site. This pattern indicates forest structure had been altered within the edge environment, in a manner similar to other forest types (Didham & Ewers, 2012; Murcia, 1995). Results

indicated a positive relationship was found for *Sequoia Sempervirens* and *Notholithocarpus densiflorus* stand density, while *Quercus wislizeni* stand density illustrated a negative correlation. Changes in stand density suggest the vegetation structure difference between the forest edge and the forest interior (Matlack, 1994). The total basal area showed a significant difference between the two treatment groups where the forest edge was higher. This outcome was unexpected since edge effects promote forest fragmentation leaving less area covered by the forest than the forest interior (Murcia, 1995). However, there was a case where the forest edge may show a higher total basal area due to increased light availability compared to the interior (de Casenave et al., 1995). As for tree species richness and evenness, there was a weak positive correlation. All tree species richness, evenness, and diversity had a higher value in the forest edge compared to the control treatment. According to the literature, species richness and diversity are higher in the forest edge and decrease towards the interior (Brothers & Spingarn, 1992; Murcia, 1995; Normann et al., 2016). A previous study explained that the edge effect may have a possibility to enhance structural diversity since the edge and the interior have different microclimates (Bieringer & Zulka, 2003).

Results suggested that the total understory species cover was significantly higher in the forest edge than in the control treatment. This phenomenon can be explained similarly to tree species richness and diversity, that forest edges tend to have greater diversity and plant species richness (Brothers & Spingarn, 1992; Murcia, 1995; Normann et al., 2016). Surprisingly, native understory species cover was higher in the forest edge areas rather than the control treatment. Higher native understory species cover in the edge may

suggest the environment within the forest edge, such as higher solar radiation, air temperature, soil temperature, and moisture have provided habitats for native species to grow successfully. *Oxalis oregana* cover had a positive relationship with the distance from the edge, however, did not show a difference between the two treatments. *Oxalis oregana* is sun-sensitive species, therefore microclimate conditions created by the canopy in the forest interior may support their growth (Lyons & Lazaneo, 2015). Furthermore, non-native species richness had a negative correlation between the distance from the edge and was statistically higher in the forest edge rather than the control site. As predicted in the literature, forest edges introduce exotic plant species (Olupot, 2009; Vallet et al., 2010). Moreover, coast redwood associates cover and richness showed a positive correlation in the forest edge site. This outcome suggests that coast redwood associates are more capable of thriving in the forest interior where there is more shade provided by the canopy cover.

## **Conclusion**

This research aimed to identify how urban edges influence soil properties and forest composition within the WUI in the Forest of Nisene Marks State Park coast redwood preserve. Based on the analysis, several correlations were indicated between variables and the distance from the edge. Moreover, various important distinctions were found between the forest edge and the control treatment within the Forest of Nisene Marks State Park, including soil properties, stand structure, and understory species composition. The urban edge effect has impacted soil characteristics and forest composition within the forest edge in the coast redwood preserves.

Further studies in the different coast redwood preserves are recommended since the research was limited to one state park within Santa Cruz Mountain. Acquiring more data on a larger scale may help better understand the impact of the urban edge effect in the coast redwood forest composition. Increasing the number of both forest edge and control treatments will enhance the datasets. In addition, collecting data during Spring and Summer seasons may develop the understory species data since more plant species are found during this period. Findings from this research may contribute to raising awareness of WUI issues to resource managers who are committed to preserving the coast redwood forest and their surrounding ecological communities.

## **Recommendations**

Continued research is highly recommended to understand the urban edge effects on coast redwood forests in depth. WUI in the United States continues to expand, and redwood forestlands will experience impacts from urbanization. Further studies in coast redwood forests in different regions would deliver strong evidence of how WUI affects the forest communities. Future guidance for forest management plans to support the success of conservation efforts and habitat protection can be expected. Especially, coast redwood forests provide essential environmental services, including creating habitats for sensitive endangered species and reducing the effects of climate change by capturing carbon dioxide. It is crucial to consider protecting coast redwoods in their remaining natural habitat on the northern pacific coast as only five percent of original forests remain due to past logging history.

## Literature Cited

- Agarwala, M., Ghoshal, S., Verchot, L., Martius, C., Ahuja, R., & DeFries, R. (2017). Impact of biogas interventions on forest biomass and regeneration in southern India. *Global Ecology and Conservation*, *11*, 213-223. <https://doi.org/10.1016/j.gecco.2017.06.005>
- Anderson, R. S. (1994). Evolution of the Santa Cruz Mountains, California, through tectonic growth and geomorphic decay. *Journal of Geophysical Research: Solid Earth*, *99*(B10), 20161-20179. <https://doi.org/10.1029/94jb00713>
- Baldwin, B. G., Goldman, D., Keil, D. J., Patterson, R., Rosatti, T. J., & Wilken, D. H. (Eds.). (2012). *The Jepson manual: Vascular plants of California* (2nd ed.). University of California Press.
- Barbour, M. G., Lydon, S., Borchert, M., Popper, M., Whitworth, V., & Evarts, J. (2001). *Coast redwood: A natural and cultural history* (2nd ed.). Cachuma Press.
- Bieringer, G., & Zulka, K. P. (2003). Shading out species richness: Edge effect of a pine plantation on the Orthoptera (Tettigoniidae and Acrididae) assemblage of an adjacent dry grassland. *Biodiversity and Conservation*, *12*(7), 1481-1495. <https://doi.org/10.1023/a:1023633911828>
- Brand, L. A., & George, T. L. (2000). Predation risks for nesting birds in fragmented coast redwood forest. *The Journal of Wildlife Management*, *64*(1), 42-51. <https://doi.org/10.2307/3802973>
- Brothers, T. S., & Spingarn, A. (1992). Forest fragmentation and alien plant invasion of central Indiana old-growth forests. *Conservation Biology*, *6*(1), 91-100. <https://doi.org/10.1046/j.1523-1739.1992.610091.x>
- Buonopane, M., Snider, G., Kerns, B. K., & Doescher, P. S. (2013). Complex restoration challenges: Weeds, seeds, and roads in a forested wildland urban interface. *Forest Ecology and Management*, *295*, 87-96. <https://doi.org/10.1016/j.foreco.2013.01.013>
- Busing, R. T., & Fujimori, T. (2002). Dynamics of composition and structure in an old Sequoia sempervirens forest. *Journal of Vegetation Science*, *13*(6), 785-792. <https://doi.org/10.1111/j.1654-1103.2002.tb02108.x>
- California Department of Parks and Recreation. (2018). *The Forest of Nisene Marks State Park* [Brochure].
- Camargo, J. L. C., & Kapos, V. (1995). Complex edge effects on soil moisture and microclimate in central Amazonian forest. *Journal of Tropical Ecology*, *11*(2), 205-221. <https://doi.org/10.1017/s026646740000866x>

- Campbell, L. (2000). *American Indian languages: The historical linguistics of Native America*. Oxford University Press.
- Christie, F. J., & Hochuli, D. F. (2005). Elevated levels of herbivory in urban landscapes: Are declines in tree health more than an edge effect? *Ecology and Society*, *10*(1). <https://doi.org/10.5751/es-00704-100110>
- de Casenave, J. L., Pelotto, J. P., & Protomastro, J. (1995). Edge-interior differences in vegetation structure and composition in a Chaco semi-arid forest, Argentina. *Forest Ecology and Management*, *72*(1), 61-69. [https://doi.org/10.1016/0378-1127\(94\)03444-2](https://doi.org/10.1016/0378-1127(94)03444-2)
- Didham, R. K., & Ewers, R. M. (2012). Predicting the impacts of edge effects in fragmented habitats: Laurance and Yensen's core area model revisited. *Biological Conservation*, *155*, 104-110. <https://doi.org/10.1016/j.biocon.2012.06.019>
- Dovčiak, M., & Brown, J. (2014). Secondary edge effects in regenerating forest landscapes: Vegetation and microclimate patterns and their implications for management and conservation. *New Forests*, *45*(5), 733-744. <https://doi.org/10.1007/s11056-014-9419-7>
- Dupuch, A., & Fortin, D. (2013). The extent of edge effects increases during post-harvesting forest succession. *Biological Conservation*, *162*, 9-16. <https://doi.org/10.1016/j.biocon.2013.03.023>
- Esseen, P. (2006). Edge influence on the old-growth forest indicator lichen *Alectoria sarmentosa* in natural ecotones. *Journal of Vegetation Science*, *17*(2), 185-194. <https://doi.org/10.1111/j.1654-1103.2006.tb02437.x>
- Gascon, C., Williamson, G. B., & da Fonseca, G. A. B. (2000). Receding forest edges and vanishing reserves. *Science*, *288*(5470), 1356-1358. <https://doi.org/10.1126/science.288.5470.1356>
- Hageseth, K. K. (2008). Vegetation change over time in naturally-regenerating coast redwood communities [Master's thesis, San José State University]. SJSU ScholarWorks. <https://doi.org/10.31979/etd.wsuc-k76x>
- Halpern, C. B., & McKenzie, D. (2001). Disturbance and post-harvest ground conditions in a structural retention experiment. *Forest Ecology and Management*, *154*(1-2), 215-225. [https://doi.org/10.1016/s0378-1127\(00\)00628-9](https://doi.org/10.1016/s0378-1127(00)00628-9)
- Hamberg, L., Lehvavirta, S., & Kotze, D. J. (2009). Forest edge structure as a shaping factor of understorey vegetation in urban forests in Finland. *Forest Ecology and Management*, *257*(2), 712-722. <https://doi.org/10.1016/j.foreco.2008.10.003>

- Hamberg, L., Lehvavirta, S., Malmivaara-Lämsä, M., Rita, H., & Kotze, D. J. (2008). The effects of habitat edges and trampling on understory vegetation in urban forests in Helsinki, Finland. *Applied Vegetation Science*, *11*(1), 83-98. <https://doi.org/10.1111/j.1654-109x.2008.tb00207.x>
- Hammer, R. B., Stewart, S. I., & Radeloff, V. C. (2009). Demographic trends, the wildland-urban interface, and wildfire management. *Society & Natural Resources*, *22*(8), 777-782. <https://doi.org/10.1080/08941920802714042>
- Hanover, A., & Russell, W. (2018). Understory recovery in coast redwood communities: A case study comparing a naturally recovering and an actively managed forest. *Open Journal of Forestry*, *08*(04), 489-499. <https://doi.org/10.4236/ojf.2018.84031>
- Hanson, J. J., & Stuart, J. D. (2005). Vegetation responses to natural and salvage logged fire edges in Douglas-fir/hardwood forests. *Forest Ecology and Management*, *214*(1-3), 266-278. <https://doi.org/10.1016/j.foreco.2005.04.010>
- Hardt, E., Pereira-Silva, E. F., dos Santos, R. F., Tamashiro, J. Y., Ragazzi, S., & Lins, D. B. D. S. (2013). The influence of natural and anthropogenic landscapes on edge effects. *Landscape and Urban Planning*, *120*, 59-69. <https://doi.org/10.1016/j.landurbplan.2013.08.014>
- Harper, K. A., Macdonald, S. E., Burton, P. J., Chen, J., Brosofske, K. D., Saunders, S.C., Euskirchen, E. S., Roberts, D., Jaiteh, M. S., & Esseen P. A. (2005). Edge influence on forest structure and composition in fragmented landscapes. *Conservation Biology*, *19*(3), 768-782. <https://doi.org/10.1111/j.1523-1739.2005.00045.x>
- Harper, K. A., Macdonald, S. E., Mayerhofer, M. S., Biswas, S. R., Esseen, P., Hylander, K., Stewart, K. J., Mallik, A. U., Drapeau, P., Jonsson, B., Lesieur, D., Kouki, J., & Bergeron, Y. (2015). Edge influence on vegetation at natural and anthropogenic edges of boreal forests in Canada and Fennoscandia. *Journal of Ecology*, *103*(3), 550-562. <https://doi.org/10.1111/1365-2745.12398>
- Hull, R. B., & Nelson, K. (2011). Wildland-urban interface forest entrepreneurs: A look at a new trend. *Journal of Forestry*, *109*(3), 136-140. <https://doi.org/10.1093/jof/109.3.136>
- Hwang, K., Han, H. S., Marshall, S. E., & Page-Dumroese, D. S. (2020). Soil compaction from cut-to-length thinning operations in young redwood forests in northern California. *Canadian Journal of Forest Research*, *50*(2), 185-192. <https://doi.org/10.1139/cjfr-2019-0225>
- Johnstone, J. A., & Dawson, T. E. (2010). Climatic context and ecological implications of summer fog decline in the coast redwood region. *Proceedings of the National Academy of Sciences*, *107*(10), 4533-4538. <https://doi.org/10.1073/pnas.0915062107>

- Jose, S., Gillespie, A. R., George, S. J., & Kumar, B. (1996). Vegetation responses along edge-to-interior gradients in a high altitude tropical forest in peninsular India. *Forest Ecology and Management*, 87(1-3), 51-62. [https://doi.org/10.1016/s0378-1127\(96\)03836-4](https://doi.org/10.1016/s0378-1127(96)03836-4)
- Kapos, V. (1989). Effects of isolation on the water status of forest patches in the Brazilian Amazon. *Journal of Tropical Ecology*, 5(2), 173-185. <https://doi.org/10.1017/s0266467400003448>
- Lebron, I., Robinson, D. A., Oatham, M., & Wuddivira, M. N. (2012). Soil water repellency and pH soil change under tropical pine plantations compared with native tropical forest. *Journal of Hydrology*, 414, 194-200. <https://doi.org/10.1016/j.jhydrol.2011.10.031>
- Levin, S. A., Carpenter, S. R., Godfray, C. H. J., Kinzig, A. P., Loreau, M., Losos, J. B., Walker, B., & Wilcove, D. S. (2012). *The Princeton guide to ecology*. Princeton University Press.
- Loya, D. T., & Jules, E. S. (2007). Use of species richness estimators improves evaluation of understory plant response to logging: A study of redwood forests. *Plant Ecology*, 194(2), 179-194. <https://doi.org/10.1007/s11258-007-9283-z>
- Lyons, K., & Lazaneo, M. B. (2015). *Plants of the coast redwood region*. Shoreline Press.
- Magurran, A. E., & McGill, B. J. (2011). *Biological diversity: Frontiers in measurement and assessment* (1st ed.). Oxford University Press.
- Malmivaara-Lämsä, M., Hamberg, L., Haapamäki, E., Liski, J., Kotze, D. J., Lehvävirta, S., & Fritze, H. (2008). Edge effects and trampling in boreal urban forest fragments - Impacts on the soil microbial community. *Soil Biology and Biochemistry*, 40(7), 1612-1621. <https://doi.org/10.1016/j.soilbio.2008.01.013>
- Matlack, G. R. (1993). Microenvironment variation within and among forest edge sites in the eastern United States. *Biological Conservation*, 66(3), 185-194. [https://doi.org/10.1016/0006-3207\(93\)90004-k](https://doi.org/10.1016/0006-3207(93)90004-k)
- Matlack, G. R. (1994). Vegetation dynamics of the forest edge - Trends in space and successional time. *The Journal of Ecology*, 82(1), 113. <https://doi.org/10.2307/2261391>
- McBride, J. R. (1977). *The ecology of redwood (Sequoia sempervirens (D. Don) Endl.) and the impact of man's use of the redwood forest as a site for recreational activities*. California Department of Forestry and Fire Protection.

- Murcia, C. (1995). Edge effects in fragmented forests: Implications for conservation. *Trends in Ecology & Evolution*, 10(2), 58-62. [https://doi.org/10.1016/s0169-5347\(00\)88977-6](https://doi.org/10.1016/s0169-5347(00)88977-6)
- National Park Service. (2003). *Fire monitoring handbook*. <https://www.nps.gov/orgs/1965/upload/fire-effects-monitoring-handbook.pdf>
- Normann, C., Tschardtke, T., & Scherber, C. (2016). How forest edge-center transitions in the herb layer interact with beech dominance versus tree diversity. *Journal of Plant Ecology*, 9(5), 498-507. <https://doi.org/10.1093/jpe/rtw004>
- Noss, R. F. (1999). *The redwood forest: History, ecology, and conservation of the coast redwoods*. Island Press.
- O'Hara, K., Cox, L., Nikolaeva, S., Bauer, J., & Hedges, R. (2017). Regeneration dynamics of coast redwood, a sprouting conifer species: A review with implications for management and restoration. *Forests*, 8(5), 144. <https://doi.org/10.3390/f8050144>
- Olson, D. F., Roy, D. F., & Walters, G. A. (1990). Sequoia sempervirens (D. Don) Endl. redwood. *Silvics of North America*, 1, 541-551. <https://dendro.cnre.vt.edu/dendrology/USDAFSSilvics/180.pdf>
- Olupot, W. (2009). A variable edge effect on trees of Bwindi Impenetrable National Park, Uganda, and its bearing on measurement parameters. *Biological Conservation*, 142(4), 789-797. <https://doi.org/10.1016/j.biocon.2008.12.015>
- Paul, K. I., Polglase, P. J., Smethurst, P. J., O'Connell, A. M., Carlyle, C. J., & Khanna, P. K. (2004). Soil temperature under forests: A simple model for predicting soil temperature under a range of forest types. *Agricultural and Forest Meteorology*, 121(3-4), 167-182. <https://doi.org/10.1016/j.agrformet.2003.08.030>
- Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., & McKeefry, J. F. (2005). The wildland-urban interface in the United States. *Ecological Applications*, 15(3), 799-805. <https://doi.org/10.1890/04-1413>
- Radeloff, V. C., Helmers, D. P., Kramer, H. A., Mockrin, M. H., Alexandre, P. M., Bar-Massada, A., Butsic, V., Hawbaker, T. J., Martinuzzi, S., Syphard, A. D., & Stewart, S. I. (2018). Rapid growth of the US wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences*, 115(13), 3314-3319. <https://doi.org/10.1073/pnas.1718850115>
- Riutta, T., Slade, E. M., Bebbler, D. P., Taylor, M. E., Malhi, Y., Riordan, P., Macdonald, D. W., & Morecroft, M. D. (2012). Experimental evidence for the interacting effects of forest edge, moisture and soil macrofauna on leaf litter decomposition. *Soil Biology and Biochemistry*, 49, 124-131. <https://doi.org/10.1016/j.soilbio.2012.02.028>

- Russell, W. (2020). Herbaceous understory indicators of post-harvest recovery in coast redwood (*Sequoia sempervirens*) forests. *Open Journal of Forestry*, *10*(02), 204-216. <https://doi.org/10.4236/ojf.2020.102014>
- Russell, W. H., & Jones, C. (2002). The effects of timber harvesting on the structure and composition of adjacent old-growth coast redwood forest, California, USA. *Landscape Ecology*, *16*(8), 731-741. <https://doi.org/10.1023/a:1014486030462>
- Russell, W., Lambert, Z., & Woolhouse, S. (2019). Old-growth characteristics on a coast redwood (*Sequoia sempervirens* (D. Don) Endl.) pygmy forest ecotone. *Madroño*, *66*(1), 14. <https://doi.org/10.3120/0024-9637-66.1.14>
- Russell, W., Sinclair, J., & Michels, K. H. (2014). Restoration of coast redwood (*Sequoia sempervirens*) forests through natural recovery. *Open Journal of Forestry*, *4*(2), 106-111. <https://doi.org/10.4236/ojf.2014.42016>
- Sampaio, A. B., & Scariot, A. (2011). Edge effect on tree diversity, composition and structure in a deciduous dry forest in central Brazil. *Revista Árvore*, *35*(5), 1121-1134. <https://doi.org/10.1590/s0100-67622011000600018>
- Shreve, F. (1927). The vegetation of a coastal mountain range. *Ecology*, *8*(1), 27-44. <https://doi.org/10.2307/1929384>
- Spyratos, V., Bourgeron, P. S., & Ghil, M. (2007). Development at the wildland urban interface and the mitigation of forest-fire risk. *Proceedings of the National Academy of Sciences*, *104*(36), 14272-14276. <https://doi.org/10.1073/pnas.0704488104>
- Stephens, S. L., & Fry, D. L. (2005). Fire history in coast redwood stands in the northeastern Santa Cruz Mountains, California. *Fire Ecology*, *1*(1), 2-19. <https://doi.org/10.4996/fireecology.0101002>
- Theobald, D. M., & Romme, W. H. (2007). Expansion of the US wildland-urban interface. *Landscape and Urban Planning*, *83*(4), 340-354. <https://doi.org/10.1016/j.landurbplan.2007.06.002>
- United States Census Bureau (2010). *QuickFacts: Aptos CDP, California*. U.S. Department of Commerce. Retrieved July 9, 2021, from <https://www.census.gov/quickfacts/fact/table/aptoscdpcalifornia/PST045219>
- Vallet, J., Beaujouan, V., Pithon, J., Rozé, F., & Daniel, H. (2010). The effects of urban or rural landscape context and distance from the edge on native woodland plant communities. *Biodiversity and Conservation*, *19*(12), 3375-3392. <https://doi.org/10.1007/s10531-010-9901-2>

## Appendix A: Mean Stand Density Among Treatments

Tree Species	Forest Edge									
	0 m		40 m		80 m		160 m		300 m	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
All species	649.35	125.26	770.31	110.64	420.17	44.40	350.14	43.20	509.29	67.88
<i>Sequoia sempervirens</i>	57.30	28.43	101.86	70.71	25.46	25.46	95.49	37.94	210.08	55.63
<i>Notholithocarpus densiflorus</i>	6.37	6.37	19.10	13.93	19.10	19.10	38.20	20.86	235.55	52.48
<i>Arbutus menzessii</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Quercus wislizeni</i>	566.59	124.43	598.42	120.12	337.41	58.62	165.52	35.89	12.73	8.76
<i>Psuedotsuga menziesii</i>	19.10	13.93	50.93	38.53	19.10	10.43	31.83	12.65	38.20	20.86
<i>Acer macrophyllum</i>	0.00	0.00	0.00	0.00	0.00	0.00	12.73	12.73	0.00	0.00
<i>Alnus rubra</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.73	12.73
<i>Unbellularia californica</i>	0.00	0.00	0.00	0.00	19.10	13.93	6.37	6.37	0.00	0.00
Control										
Tree Species	0 m		40 m		80 m		160 m		300 m	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
All Species	318.31	48.44	439.27	100.54	553.86	121.59	362.87	63.51	426.53	80.14
<i>Sequoia sempervirens</i>	82.76	39.49	171.89	109.40	216.45	108.94	146.42	60.06	38.20	20.86
<i>Notholithocarpus densiflorus</i>	44.56	28.13	70.03	28.43	171.89	79.61	120.96	37.49	108.23	32.36
<i>Arbutus menzessii</i>	0.00	0.00	6.37	6.37	12.73	12.73	0.00	0.00	25.46	14.89
<i>Quercus wislizeni</i>	165.52	37.06	152.79	40.89	140.06	33.18	63.66	37.52	248.28	70.63
<i>Psuedotsuga menziesii</i>	6.37	6.37	6.37	6.37	12.73	8.76	57.30	28.43	0.00	0.00
<i>Acer macrophyllum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Alnus rubra</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unbellularia californica</i>	19.10	19.10	31.83	18.18	0.00	0.00	0.00	0.00	6.37	6.37

## Appendix B: Mean Basal Area per Hectare Among Treatments

Tree Species	Forest Edge									
	0 m		40 m		80 m		160 m		300 m	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
All Species	83.23	23.32	79.79	18.23	79.64	25.18	77.60	19.90	164.06	37.20
<i>Sequoia sempervirens</i>	43.54	24.95	23.24	16.12	24.64	24.64	32.24	15.63	129.65	40.39
<i>Notholithocarpus densiflorus</i>	0.02	0.02	1.84	1.78	0.00	0.00	1.61	0.98	6.53	1.71
<i>Arbutus menzessii</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Quercus wislizeni</i>	35.51	6.54	40.97	8.86	41.03	11.75	8.30	2.44	1.42	1.20
<i>Psuedotsuga menziesii</i>	0.14	0.10	13.78	13.67	13.76	8.76	33.91	15.92	25.56	12.51
<i>Acer macrophyllum</i>	0.00	0.00	0.00	0.00	0.00	0.00	1.57	1.57	0.00	0.00
<i>Alnus rubra</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.95
<i>Unbellularia californica</i>	0.00	0.00	0.00	0.00	0.18	0.13	0.02	0.02	0.00	0.00
Tree Species	Control									
	0 m		40 m		80 m		160 m		300 m	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
All Species	57.68	12.56	61.56	15.08	90.02	27.58	111.47	33.73	36.73	13.05
<i>Sequoia sempervirens</i>	26.89	12.75	26.91	13.31	30.66	17.20	65.83	33.47	18.15	13.12
<i>Notholithocarpus densiflorus</i>	2.55	2.10	2.99	1.40	11.01	6.09	8.19	2.59	4.84	2.16
<i>Arbutus menzessii</i>	0.00	0.00	0.07	0.07	0.00	0.00	0.00	0.00	0.27	0.20
<i>Quercus wislizeni</i>	23.43	7.06	15.54	5.18	15.35	6.32	9.34	5.48	13.42	4.10
<i>Psuedotsuga menziesii</i>	0.99	0.99	10.04	10.04	9.05	7.93	28.16	16.57	0.00	0.00
<i>Acer macrophyllum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Alnus rubra</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unbellularia californica</i>	3.82	3.82	6.06	5.85	0.00	0.00	0.00	0.00	0.05	0.05

### Appendix C: Mean Dominance Among Treatments

Tree Species	Forest Edge									
	0 m		40 m		80 m		160 m		300 m	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
<i>Sequoia sempervirens</i>	19.76	9.07	10.00	6.88	5.00	5.00	27.66	9.31	46.35	10.86
<i>Notholithocarpus densiflorus</i>	0.00	0.00	10.03	6.88	0.00	0.00	10.58	6.24	27.45	9.65
<i>Arbutus menzessii</i>	0.00	0.00	0.00	0.00	5.00	5.00	0.00	0.00	0.00	0.00
<i>Quercus wislizeni</i>	74.90	9.80	64.89	10.86	69.52	10.14	33.69	10.08	2.58	2.37
<i>Psuedotsuga menziesii</i>	0.34	0.23	4.97	4.86	14.23	7.78	18.11	8.35	18.59	8.56
<i>Acer macrophyllum</i>	0.00	0.00	0.00	0.00	0.00	0.00	4.03	4.03	0.00	0.00
<i>Alnus rubra</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00
<i>Unbellularia californica</i>	0.00	0.00	0.00	0.00	6.25	5.09	1.59	1.59	0.00	0.00
Tree Species	Control									
	0 m		40 m		80 m		160 m		300 m	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
<i>Sequoia sempervirens</i>	18.38	8.47	21.49	8.60	22.89	9.05	24.20	9.11	14.45	7.52
<i>Notholithocarpus densiflorus</i>	10.10	6.88	8.07	5.13	15.64	7.26	32.36	10.32	16.79	8.06
<i>Arbutus menzessii</i>	0.00	0.00	1.67	1.67	0.00	0.00	0.00	0.00	6.67	5.19
<i>Quercus wislizeni</i>	50.95	11.28	47.78	10.92	44.46	10.75	10.05	6.60	46.26	10.73
<i>Psuedotsuga menziesii</i>	0.56	0.56	5.00	5.00	6.96	5.00	18.35	8.29	0.00	0.00
<i>Acer macrophyllum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Alnus rubra</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unbellularia californica</i>	5.00	5.00	6.00	5.05	0.00	0.00	0.00	0.00	0.33	0.33

## Appendix D: Observed Species During Data Collection

### Native Herbaceous Understory Species

<i>Adelinia grande</i> (pacific hound's tongue)	<i>Pentagramma triangularis</i> (goldback fern)
<i>Adenocaulon bicolor</i> (american trailplant)	<i>Polypodium californicum</i> (california polypody)
<i>Artemisia douglasiana</i> (california mugwort)	<i>Polystichum munitum</i> (western sword fern)
<i>Asuram caudatum</i> (wild ginger)	<i>Prosartes hookeri</i> (hooker's fairybells)
<i>Cardamine californica</i> (milkmaid)	<i>Pteridium aquilinum</i> (common bracken)
<i>Claytonia lanceolata</i> (western springbeauty)	<i>Ribes menziesii</i> (canyon gooseberry)
<i>Cystopteris fragilis</i> (brittle bladder fern)	<i>Sanicula crassicaulis</i> (pacific sanicle)
<i>Dryopteris arguta</i> (coastal wood fern)	<i>Satureja douglasii</i> (yerba buena)
<i>Fragaria vesca</i> (wild strawberry)	<i>Solanum Americanum</i> (black nightshade)
<i>Galium aparine</i> (bedstraw)	<i>Stachys bullata</i> (california hedgenettle)
<i>Iris douglasiana</i> (douglas iris)	<i>Tellima grandiflora</i> (fringecups)
<i>Lonicera hispidula</i> (hairy honeysuckle)	<i>Trillium ovatum</i> (pacific trillium)
<i>Maianthemum racemosum</i> (false solomon seal)	<i>Urtica dioica ssp. gracilis</i> (california nettle)
<i>Nemophila parviflora</i> (small-flower nemophila)	<i>Viola sempervirens</i> (redwood violet)
<i>Osmorhiza berteroi</i> (mountain sweet cicely)	<i>Woodwardia fimbriata</i> (giant chain fern)
<i>Oxalis oregana</i> (redwood sorrel)	

### **Native Shrub Understory Species**

*Frangula californica* (coffeeberry)

*Heteromeles arbutifolia* (toyon)

*Rosa gymnocarpa* (wood rose)

*Rubus ursinus* (pacific blackberry)

*Toxicodendron diversilobum* (poison oak)

*Vaccinium ovatum* (huckleberry)

### **Native Tree Species**

*Acer macrophyllum* (big leaf maple)

*Alnus rubra* (red alder)

*Arbutus menzessii* (madrone)

*Notholithocarpus densiflorus* (tanoak)

*Pseudotsuga menziesii* (Douglas fir)

*Quercus wislizeni* (interior live oak)

*Sequoia sempervirens* (coast redwood)

*Unbellularia californica* (california bay laurel)

### **Non-Native Species**

*Ageratina adenophora* (sticky snakeroot)

*Arum italicum* (italian arum)

*Crassula ovata* (jade plant)

*Ehrharta erecta* (panic veldtgrass)

*Hedera helix* (common ivy)

*Ilex aquifolium* (common holly)

*Mesembryanthemum cordifolium* (heart-leaf)

*Myosotis latifolia* (broadleaf forget me not)

*Oxalis pes-caprae* (bermuda buttercup)

*Stellaria media* (common chickweed)

*Tradescantia fluminensis* (small-leaf spiderwort)

*Vinca minor* (lesser periwinkle)

*Zantedeschia sp.* (calla lily)

### Coast Redwood-Associated Understory Species

*Asuram caudatum* (wild ginger)

*Dryopteris arguta* (coastal wood fern)

*Frangula californica* (coffeeberry)

*Maianthemum racemosum* (false solomon seal)

*Oxalis oregana* (redwood sorrel)

*Pentagramma triangularis* (goldback fern)

*Polystichum munitum* (western sword fern)

*Prosartes hookeri* (hooker's fairybells)

*Pteridium aquilinum* (common bracken)

*Rubus ursinus* (pacific blackberry)

*Trillium ovatum* (pacific trillium)

*Vaccinium ovatum* (huckleberry)

*Viola sempervirens* (redwood violet)