Oak succession in the Maritime Chaparral Ecosystem of the Fort Ord Natural Reserve

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ABSTRACT

Oak succession in maritime chaparral ecosystems is an uncommon occurrence. However, Fort Ord Natural Reserve in Marina, California is a study site with a unique condition of oak (*Quercus agrifolia*) succession within manzanita brush (*Ceanothus rigidus* and *Arctostaphylos pumila*). I studied factors that potentially alter the chaparral ecosystem and allow for oak succession: anthropogenic influences and human encroachment, interspecific and intraspecific interaction, and environmental gradients across the reserve. I sampled over 500 trees and recorded the position and life stage on an ordinal scale of 1-5. I used ArcMap to calculate the distance of the trees to anthropogenic factors (roads, trails), inter/intraspecific interactions (other trees, woodrat nests), and find the slope, elevation, and aspect of each tree. To determine the effect of these variables on tree presence and stage, I ran a backwards stepwise logistic regression and a multinomial regression for all stages concurrently. Upon calculating the p-values, I found a significant inverse correlation between stages 4 and 5 and the distance of the nearest tree, possibly indicating competition of oak trees. This competition would occur via root or canopy competition. I also found a significant inverse correlation between stage 1 trees and nearest wood rat (*Neotoma fuscipes)* nest distance, possibly indicating a symbiotic relationship between the tree and wood rats. The trees could act as a home or as a building material for the wood rats, and/or the wood rats could also be burying acorns leading to oak establishment. Finding the factors involved in determining oak succession allows for prediction of future oak establishment and potential to conserve the native chaparral habitat.

KEYWORDS

manzanita, fire suppression, ecosystem dynamics, Quercus agrifolia, California chaparral

INTRODUCTION

Human expansion and development results in altered ecosystem dynamics, especially in areas of maritime chaparral (Griffin 1978). Fire is considered an integral component in maintaining chaparral ecosystems (Keeley 1992b). However, in areas of human encroachment into chaparral, natural fire is suppressed without the loss of native vegetation such that the ecosystem does not see any major shifts in vegetation frequency. Despite the commonly held belief that chaparral ecosystems require fire for seedling establishment and growth, post-fire regenerating manzanita seedlings are "capable of continuously regenerating their canopy from basal sprouts", and species diversity remains evident (Keeley 1992b). Older Chaparral ecosystems in California lacking in fires maintain their native vegetation and persist for decades with minimal ecosystem alteration (Keeley 1992a). Although these areas are able to retain the majority of their chaparral despite human encroachment, suppression of fire still has lasting impacts on the overall ecosystem dynamics. Many areas experiencing long-term absence of fire retain their ecosystem diversity, but experience an alteration of proportions of different species. Although native vegetation persists, non-native species richness and abundance increases (Keeley et al. 2005) and in some maritime chaparral experiencing fire suppression, transitions to oak woodland are occurring. This transition and the factors driving the succession is the main focus of my study.

The maritime chaparral ecosystem of Fort Ord, California, is undergoing oak succession when an oak seed establishes itself within the middle of a manzanita patch, ultimately transitioning the entire ecosystem to oak woodland, indicating a facilitative yet deadly relationship (Calloway and Frank, 1998). Establishing within the manzanita patch helps the seedling to avoid herbivory; however, as the oak tree grows it outcompetes and shades out the surrounding chaparral vegetation (Lauren Fox, personal communication). Because of its proximity to human development, fire has not occurred at Fort Ord for over 50 years. Looking out at the reserve, one can see oak trees sporadically spread across the vegetation; this unique site and its history provide a framework for understanding altered ecosystem dynamics. The factors of oak woodland establishment and succession occur mainly through interspecific interactions, environmental gradient, and human encroachment.

Biological, environmental, and human development factors all may affect oak succession. Wood rats (*Neotoma fuscipes*) may be a biological factor in the seed dispersal and establishment of oak trees in the chaparral ecosystem (Jensen and Nielson 1986), and may also suppress the manzanita and other chaparral vegetation. Wood rats' location and density would play a large role in oak establishment in maritime chaparral. Human development in the form of roads and trails may hinder oak growth. Oaks may also prefer specific, mild environmental gradients and may avoid steep slopes, high elevations, or aspects lacking sun exposure. Species interactions, environmental gradients, and human development are presumably factors in oak succession; however these factors have yet to be related to the spatial arrangement of oak trees and their life stages.

The goal of this study is to determine this frequency of oak growth in the Fort Ord maritime chaparral ecosystem in Marina, California, and how environmental and human factors determine this growth pattern. Using precise locations of the oak trees in the reserve and recording the oak life stage, I examined patterns of the oak stage-frequency distribution related to human development, wood rat influence, and environmental parameters.

I hypothesize that the frequency of oak growth is concentrated in areas of high wood rat concentrations because wood rats are known to facilitate growth through spreading acorns. Alternatively, wood rats may inhibit growth because they use the branches to create their nests, stunting the growth of the tree.

I also hypothesize that human involvement may be a factor. The reserve hosts roads in which research and construction vehicles frequent, as well as storage facilities and an airport near the boundary fences. Human activity could affect the previously mentioned factors, such as animal activity, thus influencing oak tree establishment and vegetation dynamics. Alternatively, Human interaction and encroachment could have no effect on oak tree presence or stage.

METHODS

Study site

Figure 1: Map of Fort Ord Natural Reserve. The stages are shows in a gradient of green to red, corresponding to stages 1 through 5.

The Fort Ord Natural Reserve (Fig.1) is located in the city of Marina in Monterey County, off of Reservation Road near Highway 1. Marina (pop. 20,370) is about 8 miles north of Monterey and about 35 miles south of Santa Cruz. The University of California, Santa Cruz MBest center maintains and overlooks the reserve. The reserve is 60,000 acres in area, with a public park and an enclosed biological research area, where my study was conducted. The reserve hosts many endangered species in addition to manzanita and oak, including sand gilia and ceanothus. This area was used for military wilderness training of the Fort Ord Army base, decommissioned in 1994.

Data collection

To collect distribution information for analysis of vegetation frequency and characteristics, I, along with a team of fellow undergraduates supervised by Professor Laurel Fox (University of

California, Santa Cruz), compiled over 700 data points of oak tree locations over 6 areas of the reserve. The reserve has been separated into distinct polygons, approximately 30 square acres each. Our project focused on polygons with data previously collected on earlier research projects by Fox.

Vegetation

To collect information on the distribution and stage-frequency of the oak trees, I surveyed predetermined areas of the reserve and collected information of every oak tree above ten feet on each of those areas. We recorded the GPS location and the life stage of each tree and converted these locations to discrete points on a GIS map. The vegetation dataset consists of GPS data points collected with a standard Garmin tracker, and we recorded the error presented by the Garmin (in feet). The data points represent the location of individual oak trees within manzanita patches across the reserve. I recorded information on the individual tree (coordinates), and determined a life stage of the tree, with possible stages being in 0.5 intervals between 1 and 5 (Table 1).

Table 1: Summary of oak tree life stages

Life Stage	Criteria	Representative Sample

1	Oak tree is relatively small (about 10 feet) and beginning to grow within the manzanita patch. Surrounded by live manzanita.	
2	oak tree is taller, with a full canopy and no manzanita and little vegetation besides poison oak underneath	
3	Less dense of a canopy, possible some vegetation growing underneath	
4	Very little canopy, vegetation growth underneath	
5	No canopy, no leaves, end of life stage.	

Interacting Species

To determine the correlation of wood rat nests to the frequency and life stage of oak trees, I used GPS data points on wood rat nest locations to test proximity in ArcMap. I used the data from earlier projects (Laurel Fox, unpublished data). The dataset includes coordinates of wood rat nests and recorded the GPS coordinates of each one, converting each location to a discrete point in GIS. This data set does not include whether or not the nest is occupied or abandoned. With this information, I determined the distance of the oaks from the wood rat nests and graphed the resulting statistics, correlating the life stage of the oaks with their distance from the nests.

To determine the relationship between oak trees and the closest neighboring oak tree, I used ArcMap to calculate the near distance of oak tree points to oak tree points. Each point is discrete. With this information, I was able to use statistical methods to test the correlation between oak tree life stage and the proximity of nearby oaks.

Anthropogenic Factors

To test the effect of anthroprogenic development factors on the frequency and stage of oak trees, I collected data from the United States Department of Agriculture on surrounding roads (http://datagateway.nrcs.usda.gov/) and marked the trails by creating lines in ArcMap. Currently available GIS data sets of Fort Ord allow for the identification of surrounding roads and highways and their potential effect on oak frequency through identifying them as discrete points in the datasets. With the building and trail data, I determined the distance from the oak trees and graphed the life stage of the oaks with their distance from the trail and road lines.

Physical and Environmental Variables

To assess the environmental effect on the stage frequency distribution of the oaks, I collected National Elevation Dataset and soil data from the USDA website (http://datagateway.nrcs.usda.gov/). The GIS component of this analysis consisted of creating individual layers with the aspect, elevation, and slope layers and their continuous gradients. Aspect describes the direction the face of the slope is facing and slope data allows us to analyze the percent steepness. More north-facing slopes experience more moisture while more south facing slopes are drier (Colbert et al., 2003), due to differences in sun exposure. Soil data is comprised of very large polygons, and our entire reserve resided in a single polygon, allowing for no variation in soil type. Because of this, I decided not to analyze soil data.

With the slope, aspect, and elevation data, I determined the individual values for each oak tree. Slope is in degrees, aspect is in degrees, and elevation is in meters.

Data Analysis

To determine the significance of our vegetation, interspecific interaction, and anthropogenic factor variables in influencing oak tree succession, I used preexisting GIS datasets from Professor Fox as well as collected data points to produce composite maps showing relationships among the individual factors. Using the values extracted through GIS and with the life stage and oak characteristics, I used R to examine correlation using backwards stepwise logistic regression and multinomial regression analysis. This analysis consists of the stage of the tree as the response variable, with environmental gradient, interspecies, and anthropogenic factors as predictor variables. The environmental factors are referred to as "environmental variables" and the interspecies and anthropogenic variables are hereafter referred to as "biological surroundings".

Logistic Regression Model

I extracted the data from the ArcMap attribute table relating each stage to each predictor variable. To determine the significance of each variable in determining the probability of each stage, I ran a backwards stepwise multiple logistic regression model. I ran two separate models for each tree stage, one for environmental factors of aspect, slope and elevation, and one for the impact of the distance of biological factors to total ten models. Each stage followed the logic as follows: for the environmental model, the stage outcome variable = aspect + elevation + slope input variables; for the biological model, the stage outcome variable = distance of wood rat nest + distance of nearest tree + distance of nearest trail + distance to nearest road. To run the model, I converted each tree stage to binary (presence/absence), with 1 being presence and 0 being absence of that stage. Because intermittent stages existed between each integer, I grouped them as follows:

Stages 1 and 1.5: Recoded as stage 1

Stage 2:	Recoded as stage 2
Stages 2.5 and 3:	Recoded as stage 3
Stages 3.5 and 4:	Recoded as stage 4
Stages 4.5 and 5:	Recoded as stage 5

Multinomial Logit Model

Using the extracted table from ArcMap, I used each stage as an outcome variable, and each attribute as a predictor variable to determine the significance of the predictor variable in predicting the outcome variable. I used stage 1 as the baseline with which all other stages are to be compared, hence the absence of stage 1 in table x. The environmental model was the stage outcome variable = aspect + environmental + slope input variables. The biological model was the stage outcome variable = distance of wood rat nest + distance of nearest tree + distance of nearest trail + distance to nearest road. In this case, the stages are not binomial as they were in the logistic regression.

RESULTS

R analysis of Landscape variables

The raw data of the landscape variables, including environmental and biological surrounding parameters, consists of standard deviation and mean. All results are using R commander (Fox 2005). The slope mean ranged from 4.7 degrees in stage 4.5 to 7.4 degrees in stage 3.5. The aspect mean ranged from 140.7 degrees in stage 4.5 to 175.9 degrees in stage 1.5. The elevation mean ranged from 41.6 meters in stage 1.5 to 45.8 meters in stage 4.5. The mean of the distance of the nearest woodrat nest ranged from 44.2 meters in stage 4.5 to 94.6 meters in stage 5. The mean of the distance to the nearest road ranged from 127.9 meters in stage 3.5 to 193.5 meters in stage 1.5. The mean of the distance to the nearest trail ranged from 42.7 meters in stage 1 to 60.7 meters in stage 4.5. The mean of the distance to the nearest tree ranged from 7.5 meters in stage 4.5 to 12.2 meters in stage 1.5.

The frequency distribution of the input parameters (Fig. 2, slope, aspect, and elevation) and the frequency distribution of the output parameter (Fig. 3, stage) visualize the most common variables across the reserve.

Table 2: Means and standard deviations of environmental and distance variables. The mean of each stage is denoted by the top number in each cell, and the standard deviation is denoted by the bottom number in each cell.

	Environmental variables impact model			**Biological surroundings impact model**			
Stage	Slope	Aspect	Elevation	Distance to Nearest woodrat nest	Distance to Nearest Road	Distance to Nearest Trail	Distance to Nearest Tree
1	5.75 3.81	166.79 95.97	43.46 4.34	54.21 73.13	183.36 113.26	42.66 48.19	11.33 4.61
1.5	5.36 4.16	175.93 93.54	41.64 4.34	53.50 66.85	193.47 111.64	44.42 37.74	12.20 3.96
2	6.66 4.78	167.73 95.92	42.96 4.27	73.33 66.53	156.52 107.16	47.32 38.29	10.92 4.49
2.5	6.80 4.23	164.45 91.62	42.88 4.39	72.33 66.18	153.73 108.94	43.88 36.16	10.56 4.57
3	6.07 5.12	148.38 84.21	43.12 4.22	81.21 67.59	153.56 112.56	51.10 42.64	10.63 4.17
3.5	7.35 3.93	164.00 90.63	44.32 4.09	90.21 66.18	127.88 94.36	49.39 34.32	10.17 3.62
4	6.70 5.14	162.70 85.79	43.65 3.50	69.35 69.59	156.57 99.66	51.85 43.29	8.36 3.10
4.5	4.67 2.25	140.67 105.48	45.83 1.33	44.18 47.61	172.93 47.15	60.65 41.20	7.49 1.23
5	5.85 4.91	171.45 74.27	43.10 4.04	94.55 67.50	137.15 109.89	60.57 38.69	8.65 3.47

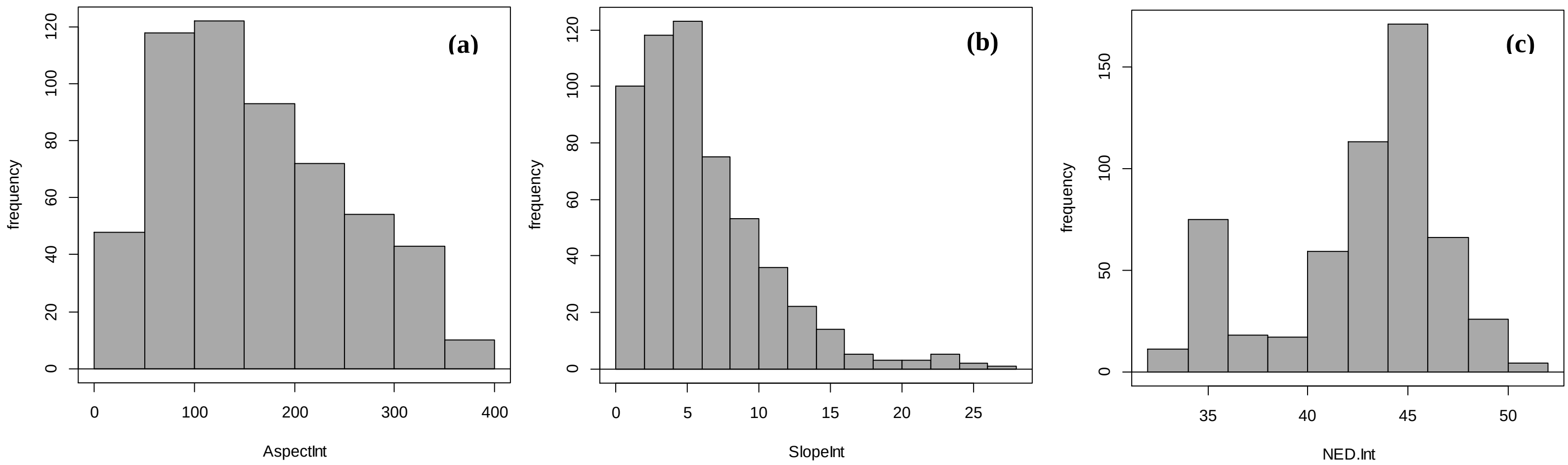

Figure 2: The frequency distribution of (a) aspect, (b) slope, and (c) elevation. Here we can visualize the distribution of the environmental parameters and the general range which oak trees persist.

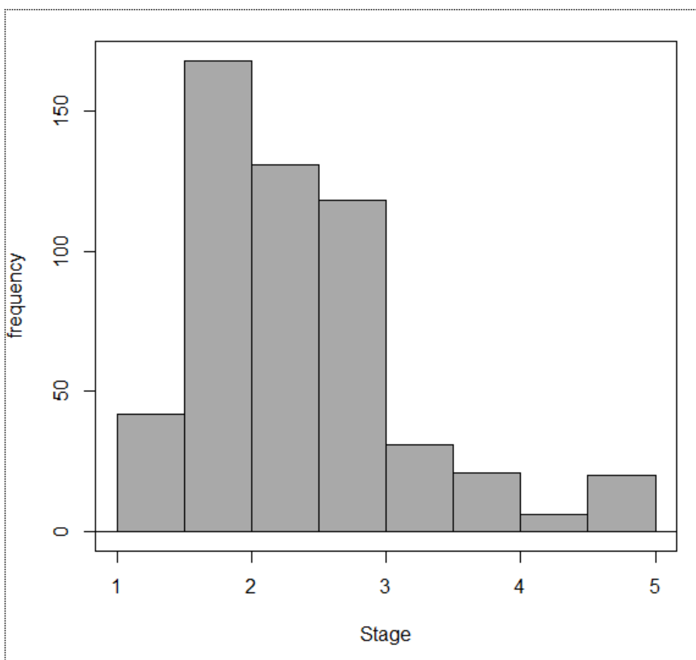

Figure 3: The frequency distribution of stages across the reserve. Here we can visualize the most common stages found across the reserve.

Logistic Regression Model:

Three models were significant for stages 1, 4, and 5 (Table 3). Stage 1 presence probability increased as wood rat nest distance decreased (Table A1 (appendix), p = 0.0412). Stage 4 (Table A4 (appendix), p = 0.04701) and stage 5 (Table A5 (appendix), p = 0.00554) presence probability increased as nearest tree distance decreased.

Table 3: Summary table of significant p-values, as taken from tables x-y in appendix. A "-" indicates no significant p-value for that stage for that variable. A number with a "*' indicates a significant p-value.

	Environmental variables impact model			Biological surroundings impact model			
Stage	Slope	Aspect	Elevation	Distance to Nearest woodrat nest	Distance to Nearest Road	Distance to Nearest Trail	Distance to Nearest Tree
1	-	-	-	**0.0412***	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	**0.04701***
5	-	-	-	-	-	-	**0.00554***

*****P-value is less than 0.05

Multinomial Logit Model

Three values were significant (P < .05) in the multinomial logit model (Table 4). Stage 4, 4.5, and 5 were significantly correlated with distance to the nearest tree, reflecting results from the logistic regression model. The resulting negative coefficients (Table 5) for stages 4, 4.5, and 5 reflect the inverse correlation between the tree stage and distance to the nearest tree.

Table 4: Resulting P-values of multinomial logit model. All results use stage 1 as a baseline.

Environmental variables impact model	Biological surroundings impact model

Stage	Slope	Aspect	Elevation	Distance to Nearest woodrat nest	Distance to Nearest Road	Distance to Nearest Trail	Distance to Nearest Tree
1.5	0.946	0.733	0.077	0.833	0.701	0.867	0.591
2	0.277	0.821	0.132	0.443	0.890	0.902	0.765
2.5	0.235	0.910	0.113	0.503	0.713	0.602	0.438
3	0.727	0.349	0.466	0.186	0.701	0.986	0.589
3.5	0.228	0.953	0.328	0.414	0.546	0.785	0.381
4	0.470	0.925	0.932	0.931	0.586	0.670	**0.008***
4.5	0.421	0.420	-	0.161	0.331	0.128	**0.045***
5	0.882	0.837	0.633	0.314	0.908	0.667	**0.027***

*****P-value is less than 0.05

-There is no significant predictive value for elevation for stage 1 vs. 4.5

Table 5: Resulting coefficients of multinomial logit model. All results use stage 1 as a baseline.

	Environmental variables impact model			**Biological surroundings impact model**			
Stage	Slope	Aspect	Elevation	Distance to Nearest woodrat nest	Distance to Nearest Road	Distance to Nearest Trail	Distance to Nearest Tree
1.5	-0.006	0.001	-0.094	0.002	0.002	0.002	0.032
2	0.055	0.001	-0.038	0.004	-0.0003	-0.001	-0.013
2.5	0.061	0.0002	-0.042	0.004	-0.001	-0.004	-0.034
3	0.017	-0.002	-0.022	0.008	0.001	-0.0001	-0.024
3.5	0.072	-0.0001	0.046	0.006	-0.002	-0.002	-0.055
4	0.057	0.0001	0.006	-0.001	-0.002	0.004	-0.240
4.5	-0.107	-0.004	-0.107	-0.023	-0.006	0.024	-0.333
5	0.011	0.001	0.011	0.008	0.005	0.004	-0.202

DISCUSSION

Oak succession in Fort Ord—brought on by the lack of fire in the area—proliferates through a variety of external variables. The stage and wellness of the tree can be predicted by surrounding factors. Stages 4 and 5, trees without canopy or signs of growth, are associated with close proximity to other trees. Stages 1, young and budding trees, are associated with close proximity to wood rat nests. These factors provide insight into the inner workings of the reserve and the dynamic process of vegetation frequency alteration.

Oak trees in Fort Ord were generally located on site with lower slopes, an aspect of approximately 45 degrees (northeast), and an elevation of 100 meters (Figure 2a-c). Lower slopes are typical of oak trees, however aspect of the slope is important (Stage 1976), as more north-facing slopes experience more moisture content and allow for the success of oak trees (Colbert et al., 2003). In future studies, these two variables should be combined for a more comprehensive analysis. Oak also prefer lower elevation sites (Kimura et al. 1989), similar to here in Fort Ord. Although it is possible that these frequencies are because the landscape is generally uniform in these variables, we can still characterize the Fort Ord oak trees as typical of oak trees. Identifying where on the reserve these numerical ranges fall may allow for prediction of suitable habitat for future oak establishment.

Wood rat nests are a significant predictor variable in predicting the presence of smaller, stage 1 trees. Stage 1 association with wood rat nests could be the result of two separate circumstances: (a) the possibility of wood rats establishing themselves near stage 1 trees, or (b) stage 1 trees establishing as a result of wood rat nests. Wood rats establishing near stage 1 trees could result from the abundance of manzanita still near the base of the tree. Wood rats use the hearty branches for their nests and often establish within the manzanita itself (Vogl 1967). Wood rats also prefer the leaves of oak for consumption (Atsatt and Ingram 1983), and because the branches are close to the ground, wood rats may more easily establish, since they are able to more easily reach a food source. The proliferation of stage 1 trees resulting from near wood rat nests could result from the habitual burial of acorns by wood rats, resulting in oak establishment (Horton and Wright 1944).

Because we do not know the true ages of the separate life stages, we cannot be sure that stages 4 and 5 are simply old and dying, however tree competition may be an appropriate underlying mechanism. Crowding of trees could result in resource competition such as intraspecific root competition, through exploitation (reducing surrounding resources) or interference competition (inhibiting resource uptake of other roots) (Schenk, 2006). This lack of success may also result from canopy competition, where reduced sun exposure as a result of shading from other trees leads to the degeneration of the outcompeted tree—just as the growth of a seedling is dependent on light and reduced canopy cover (Houseal 1997). Stage 2 trees have the largest canopies, making them the strongest competitors for canopy cover. Because stages 4 and 5 have the least amount of canopy, they may be outcompeted for canopy cover due to increased proximity to the stages with more canopy cover (stages 1-3).

The anthropogenic factors tested in my model—the proximity to trails and roads—returned insignificant results. This may be due to insignificant numbers of roads and trails, or because the proximity to these areas has no effect on the stage of the tree.

The most common stage range across the reserve is between 1.5 and 2.5 (Fig. 3). Because these stages are indicative of the most thriving and successful trees, the reserve may be seeing just the beginning of oak woodland establishment. Although fire suppression started decades ago, we are seeing the extent of its consequences today. The most prosperous stages are the most abundant, indicating overall success of oak proliferation. I was unable to include fire as a variable in this study, however looking at external variables (other than fire) indicates the future of oak succession and where oaks are likely to propagate. The current conditions of Fort Ord and its ecosystem increase its chances of vegetation alteration. Fort Ord is facing a future of oak woodland overtaking the current native maritime chaparral ecosystem, considering the current success of oaks.

Limitations

Although biological data regarding oak stage and characteristics was detailed, physical habitat information was less complete. Available soil data was not detailed enough to include the variance across the landscape—this variance could be another factor associated with oak stage and growth. Another important aspect of the reserve, the distribution and abundance of manzanita, would be an important variable to consider when looking for future establishment site of oaks. Details of crown and root competition are incomplete and incomprehensive, and knowing these details is crucial considering the importance of this competition in oak success. Our study design also could have been different; we could have done random tree sampling across the entire landscape rather than the comprehensive tree sampling across ~15% of the landscape.

Future Directions

Because we only have one summer's worth of data, creating a long-term study on the general ecosystem dynamics and range of oak tree succession would allow for a more comprehensive overview of the area over time. If we relate this data to older NED data of Fort Ord, we could see the rate and areas of expansion of oaks for possibly hundreds of years. Topographical and vegetation imagery exists as far back as 1941, and combining the NDVI data over the years to reveal a comprehensive map of the reserve over time would reveal the rate and range of oak expansion. We would compare the rate of manzanita loss to the rate of oak success and see the impact of oak succession.

Broader Implications

Fire suppression in chaparral communities can ultimately cause an ecological shift in vegetation frequency (Griffin 1978). Oak succession is the result of fire suppression, and fire suppression is ultimately the result of human influence. Following this logic, we can conclude that human actions have resulted in this ecosystem alteration. Retaining ecosystem diversity is an integral part of reducing human impact on the earth (Hobbs et al.) and in order to do so, humans must refrain from inhibiting natural occurrences, such as fire. Fire can hurt the establishment of humanity, yet it is integral in maintaining the ecosystems of which is it part. This study looked at the reasons oak trees are proliferating and succeeding—this is a study that would not exist without human encroachment and ecosystem suppression.

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APPENDIX A: Logistic Model for each Stage

Table A1: Stage 1 Logistic Regression model: The lowest p-value and the only below the .05 significance threshold was the distance to the nearest wood rat nest.

		Estimate	Standard Error	Z value	Pr(>|z|)
Environmental variables impact model	Aspect	0.0007405	0.0017394	0.426	0.670
	Slope	-0.04999	0.04011	-1.246	0.213
	Elevation	-0.0087542	0.0377085	-0.232	0.816
Biological surroundings impact model	Distance to Nearest Woodrat Nest	-0.005505	0.002696	-2.042	**0.0412***
	Distance to Nearest Road	0.001156	0.002244	0.515	0.606
	Distance to Nearest Trail	0.001443	0.005154	0.280	0.780
	Distance to Nearest Tree	0.043513	0.030940	1.406	0.1596

*****P-value is less than 0.05

Table A2: Stage 2 Logistic Regression model: No significant p-values for predictor variables.

		Estimate	Standard Error	Z value	Pr(>|z|)
Environmental variables impact model	Aspect	0.001036	0.001021	1.015	0.31
	Slope	0.015347	0.020162	0.761	0.447
	Elevation	-0.015356	0.022219	-0.691	0.490
Biological surroundings impact model	Distance to Nearest Woodrat Nest	-0.0004293	0.0014182	-0.303	0.762
	Distance to Nearest Road	-2.771e-05	1.430e-03	-0.019	0.985
	Distance to Nearest Trail	0.0002875	0.0027264	0.105	0.916
	Distance to Nearest Tree	0.02291	0.02121	1.080	0.2801

Table A3: Stage 3 Logistic Regression model: No significant p-values for predictor variables.

		Estimate	Standard Error	Z value	Pr(>|z|)
Environmental variables	Aspect	-0.001347	0.000961	-1.402	0.161
	Slope	-0.0041304	0.0191943	-0.215	0.830

	Elevation	-0.0122658	0.0205772	-0.596	0.551
Biological surroundings impact model	Distance to Nearest Woodrat Nest	0.0014605	0.0014877	0.982	0.326
	Distance to Nearest Road	0.0002161	0.0013495	0.160	0.873
	Distance to Nearest Trail	-0.0016249	0.0025263	-0.643	0.520
	Distance to Nearest Tree	0.0064645	0.0208071	0.311	0.756

Table A4: Stage 4 Logistic Regression model: The lowest p-value and the only below the .05 significance threshold was the distance to the nearest tree.

		Estimate	**Standard Error**	**Z value**	**Pr(>|z|)**
Environmental variables impact model	Aspect	0.0002532	0.0016308	0.155	0.87664
	Slope	0.02554	0.02977	0.858	0.39079
	Elevation	0.06577	0.03825	1.720	0.08547
Biological surroundings impact model	Distance to Nearest Woodrat Nest	-0.0007013	0.0038530	-0.182	0.8556
	Distance to Nearest Road	-0.001496	0.001420	-1.053	0.2921
	Distance to Nearest Trail	0.0005426	0.0038042	0.143	0.8866
	Distance to Nearest Tree	-0.08671	0.04366	-1.986	**0.04701***

*****P-value is less than 0.05

Table A5: Stage 5 Logistic Regression model: The lowest p-value and the only below the .05 significance threshold was the distance to the nearest wood rat nest.

		Estimate	**Standard Error**	**Z value**	**Pr(>|z|)**
Environmental variables impact model	Aspect	-0.0001086	0.0021743	-0.050	0.9602
	Slope	-0.05135	0.05066	-1.014	0.311
	Elevation	0.04759	0.05128	0.928	0.3534
Biological surroundings impact model	Distance to Nearest Woodrat Nest	-0.0006571	0.0035182	-0.187	0.85183
	Distance to Nearest Road	-0.0009829	0.0032297	-0.304	0.76088
	Distance to Nearest Trail	0.006785	0.004684	1.449	0.14747
	Distance to Nearest Tree	-0.20846	0.07516	-2.774	**0.00554***

*****P-value is less than 0.05

APPENDIX B: Probability Graphs for significant P-values for the Logistic Regression Model

Figure B1: Probability graph of stage 1 in relation to the distance to the nearest wood rat nest

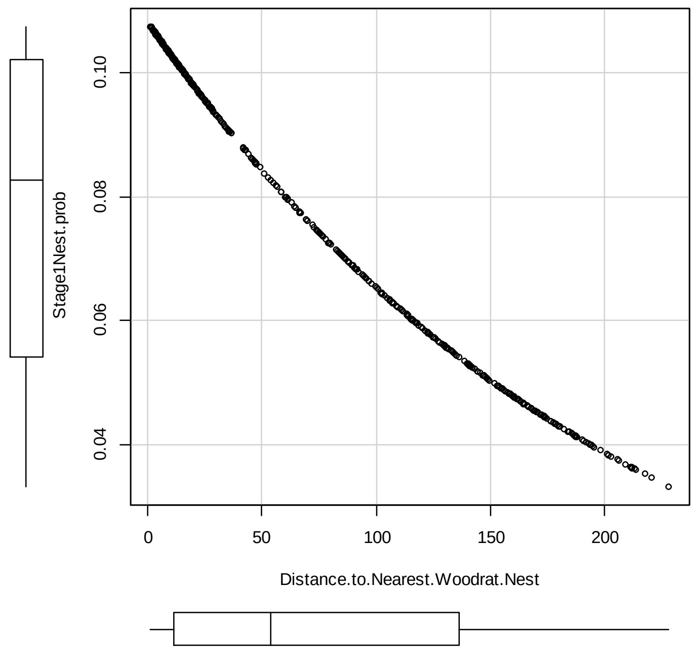

Figure B2: Probability graph of stage 4 in relation to the distance to the nearest oak tree

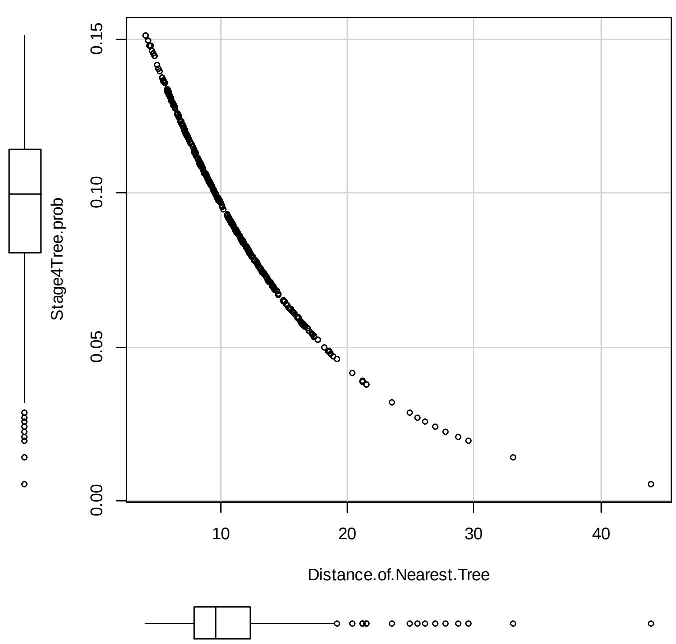

Figure B3: Probability graph of stage 5 in relation to the distance to the nearest oak tree