Investigating meter scale topographic variation as a factor of Monterey pine (*Pinus radiata*) growing conditions at Kenneth Norris Rancho Marino Reserve, Cambria, CA

A Senior Project Presented to

The Natural Resource and Environmental Science Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment of the Requirements for the Degree

Earth Science; Bachelor of Science

By

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June 2014

APPROVAL PAGE

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ACKNOWLEGEMENTS

I would like to dedicate this section to giving thanks and appreciation to the people that helped make this project possible. I thank Professor Antonio F. Garcia for over-seeing this work as my project advisor, providing me with information and guidance through the sometimes frustrating-yet rewarding aspects of field-based work. I thank reserve manager Don Canestro for providing me with tools, information, and flexible access to the reserve over the months. I thank Earth Science Major Sam Monsalve for assisting me with field work on the reserve. I want to thank my friends and family for their support during this experiment. I would like to thank the Department of Natural Resource and Environmental Science (NRES) and technician Craig Stubler for providing equipment and guidance. I thank the College of Agriculture, Food, and Environmental Science (CAFES) for its services over the years. Last but not least, I thank California Polytechnic State University itself for 5 amazing years of “learn by doing” education.

ABSTRACT

Endemic Monterey pine (*Pinus radiata*) is limited to three locations in California due to its unique ecological requirements. This project was conducted to investigate spatial growth patterns of Monterey pine over complex ground surfaces. The coastal hills of Rancho Marino Reserve, Cambria, were surveyed using four 150-m transects to quantify and record ground surface features and growing conditions of Monterey pine. Changes in elevation of each transect were measured using an Abney level. Linear ground surfaces were found at 86% (344 of 400) of survey nodes. Convex ground surfaces were found at 10.5% of survey nodes (42 of 400). Of the 50 trees that were encountered, 54% grew on linear surfaces and 44% grew on convex surfaces. Calculations of elevation changes were inconclusive due to error. Complex meter scale variations in the ground surface influence the spatial extent of Monterey pine trees at Rancho Marino. The trees likely prefer higher porosity levels associated with linear and convex soil surfaces. Monterey pine may have played a first-hand role in recent landscape evolution at Rancho Marino.

CONTENTS

1. INTRODUCTION

Monterey pine (*Pinus radiata*), a versatile fast-growing source of medium density softwood, is the most cultivated pine tree species in the world (Canestro, oral comm., 2014). The 2,500 acre stand of *Pinus radiata* in Cambria is the southern-most extent of the species in California, and is one of three remaining major endemic stands that remain today. Other notable stands are located in Monterey on the Monterey Peninsula (10,000 acres) and in Santa Cruz at the Cal Poly operated Swanton Pacific Ranch (1,000 acres) (Douglas, 1966). The pines at the Kenneth S. Norris Rancho Marino Reserve (Fig. 1) allow researchers and land managers the opportunity to observe succession of the species with minimal interference from human activity. Research studies addressing the negative impacts of drought conditions and diseases on *Pinus radiata* populations are critical due to climbing mortality rates of the trees (Canestro, oral comm., 2014).

While drought and disease greatly affect the pines, other inherent growing conditions such as local geology, soil conditions, and geomorphic regimes, may also significantly affect short- and long-term success or failure of the species at Rancho Marino. It is suspected that geomorphic conditions underlying the soil surface at distinct locations are but one of the many factors controlling the limited extent of Monterey pine along the range front at the reserve. The trees themselves may in turn affect the ground surface and sub-surface, directly influencing the rate at which pedogenesis occurs (Roering *et al.,* 2007). Slight variations in the shape of the soil surface have the potential to significantly alter hydrologic conditions, erosion rates, and landscape dynamics (Thompson *et al.,* 2010; O'Farrel *et al.,* 2007). In a previous study, Kabrick *et al.* (1997) cites that concavities in the soil surface collect more leaf litter and moisture than convexities, and that pine growth is significantly greater on convex components of the soil (as cited in Beatty and Stone, 1986; Lyford and McLean, 1966). Portions of the range front at Rancho Marino covered by Monterey pine may exhibit characteristics of pit-and-mound topography, a phenomenon associated with tree-turnover in which the ground surface geometry is characterized by concavities and convexities created by mechanical alteration during tree-throw events (O'Farrel *et al.,* 2007; Phillips and Marion, 2006).

The goal of this project is: 1) to investigate a possible connection between the distribution of Monterey pine trees and the complex ground surfaces on which they grow; 2) to provide reserve managers with useful data for land use planning; and, 3) to create a launching pad for future senior projects and related studies at Rancho Marino. In this project, a cost-effective methodology adapted from Kabrick *et al.* (1997) was used to survey meter-scale topography and surface shape along the range front at Rancho Marino. Residents of Cambria living within close proximity to Monterey pine trees are subject to property damage and risk of personal injury from toppling trees. Thus, tree-throw and its associated soil conditions are a particularly important aspect of this project. Ideally, results will further elaborate on the preferred niche conditions of Monterey pine at Rancho Marino, and perhaps substantiate the need for other studies aiming to quantify or empirically document the effects of geomorphology on forest succession and vice versa.

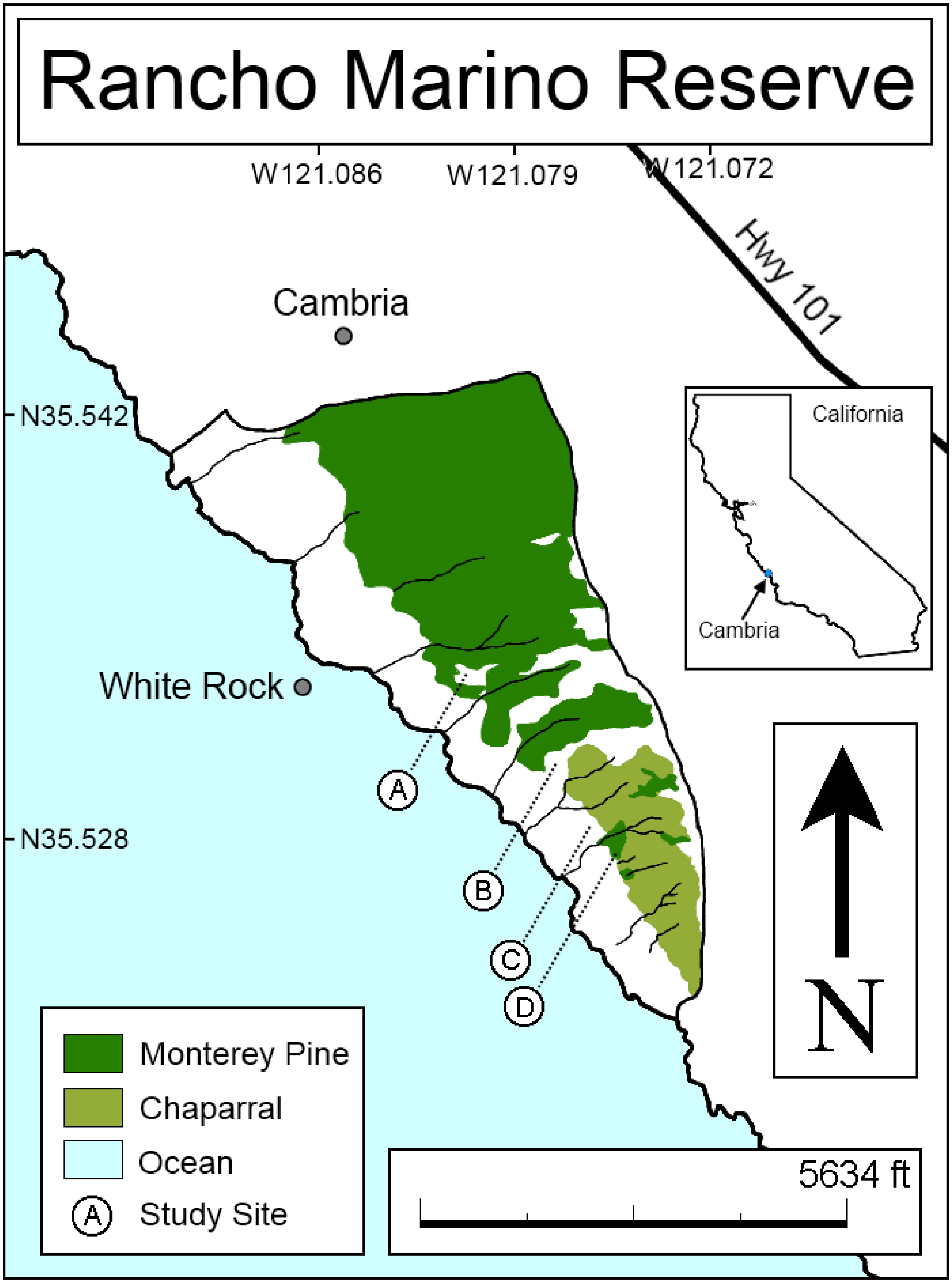

Figure 1. Map of Rancho Marino Reserve and study site locations.

2. MATERIALS AND METHODS

2.1 *Study Site*

The terrain in the Kenneth S Norris Rancho Marino Reserve (~2,000km^2) formed in an unnamed geologic unit informally known as the Cambria Slab. The unit is late Cretaceous in age and formed as a trench-slope-basin component of the Franciscan Complex mélange (Stokes and Garcia, 2010). The Franciscan Complex is a geologic unit composing a vast amount of the central coast in California (Stokes and Garcia, 2010). The Cambria Slab is a sequence of inter-bedded sandstone, shale and mudstone (Stokes and Garcia, 2009). Landscape evolution has been primarily controlled by alluvial fans prograding over a series of marine terraces (Stokes and Garcia, 2009). Today, the landscape at Rancho Marino is typified by gentle slopes in the northwest with a mean range front gradient of 0.1 and steeper slopes in the southeast with a mean range front gradient of 0.36 (Stokes and Garcia, 2009).

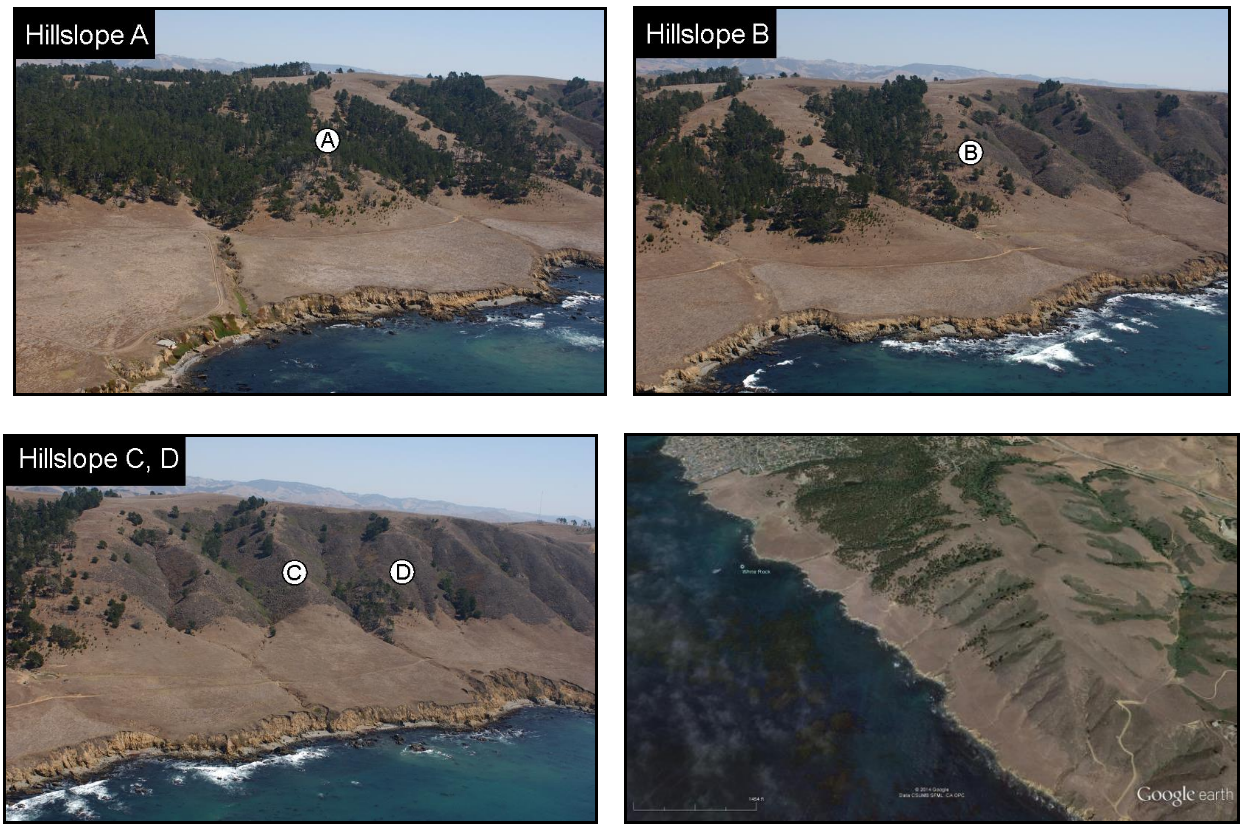

Figure 2. Top row and bottom-left photo show hill slopes A, B, C, and D where microtopography and Monterey pine distribution was surveyed. Bottom-right photo is a digital elevation model (DEM) showing the gradient from Monterey pine in the north-west to coastal scrub in the south-east. Photos of Rancho Marino courtesy of California Coastal Records Project; Photo 4 and DEM courtesy of Google Earth.

Vegetation distributions at Rancho Marino are variable along the range front (Fig. 2), grading from Monterey pine on the gentle slopes in the north-west to predominantly coastal scrub on the steep slopes in the south-east. An abrupt contact between grassland species' and scrub and forest plant types roughly delineates the transition from the marine terraces to the lower foot of the range front.

The grassland-chaparral-forest continuum is a highly diverse area that is serves as an ecotone- an area of ecological convergence in which biodiversity is greatest due to the high amount of species growing and living within proximity to each other. Ecotones at Rancho Marino may have fluctuated over time as a result of landscape evolution. What is seen today is a snap shot in time of a continual competition for resources between the three ecotypes. It is suspected that a distinct difference in curvature of the soil surface exists at a quantifiable scale between areas of differing slope and vegetative cover at the reserve. The methods developed in this project are intended to test the notion that identifiable variations in the soil surface are present, and further, continually affect the presence of Monterey pine trees and other plant species at Rancho Marino.

A)

B)

Figure 3. A) Break from grass-dominated vegetation to tree-dominated vegetation on hill-slope A. Note the hummocky appearance of the ground surface beneath the tree canopy. **B)** Coastal scrub dominated hill-slope; hill-slope B. Note the steep, linear shape of the range front morphometry on the brushy hill sides.

2.2 *Transect Dimensions and Coverage*

On the drumlinized landscape of north-east Wisconsin, Kabrick *et al.* (1997) concluded that the most efficient method to accurately estimate pit and mound topography is surveying the ground surface for pits, mounds, and flat ground every 3-m along four, 300-m transects. Survey of pit-and-mound topography was conducted visually due to easily recognizable pit-and-mound features. Assuming pit-and-mound topography indicates the occurrence of tree-throw, their method can be applied in other scenarios to accurately estimate the percentage of tree-throw affected surfaces on soil map units (Kabrick *et al,* 1997).

In this project, four hill slopes were investigated (Fig. 1, 2) using a methodology adapted from Kabrick *et al.* (1997) to survey microtopographic variations and tree-soil interactions with the greatest accuracy and efficiency. We assessed the differences in study site conditions between north-eastern Wisconsin and Cambria by modifying the layout of each transect. The design is intended to survey microtopography and the distribution of Monterey pine in two dimensions along the range front. Four, 150-m transects with 30-m perpendicular intersects every 30-m (300-m distance total) (Fig. 3) were lain out on hill slopes A, B, C, and D. Starting elevations are 75-ft, 120-ft, 170-ft, and 160-ft respectively. The initial nodes of each transect were placed at relatively low elevations to include portions of the alluvial fans overlying marine terraces at Rancho Marino.

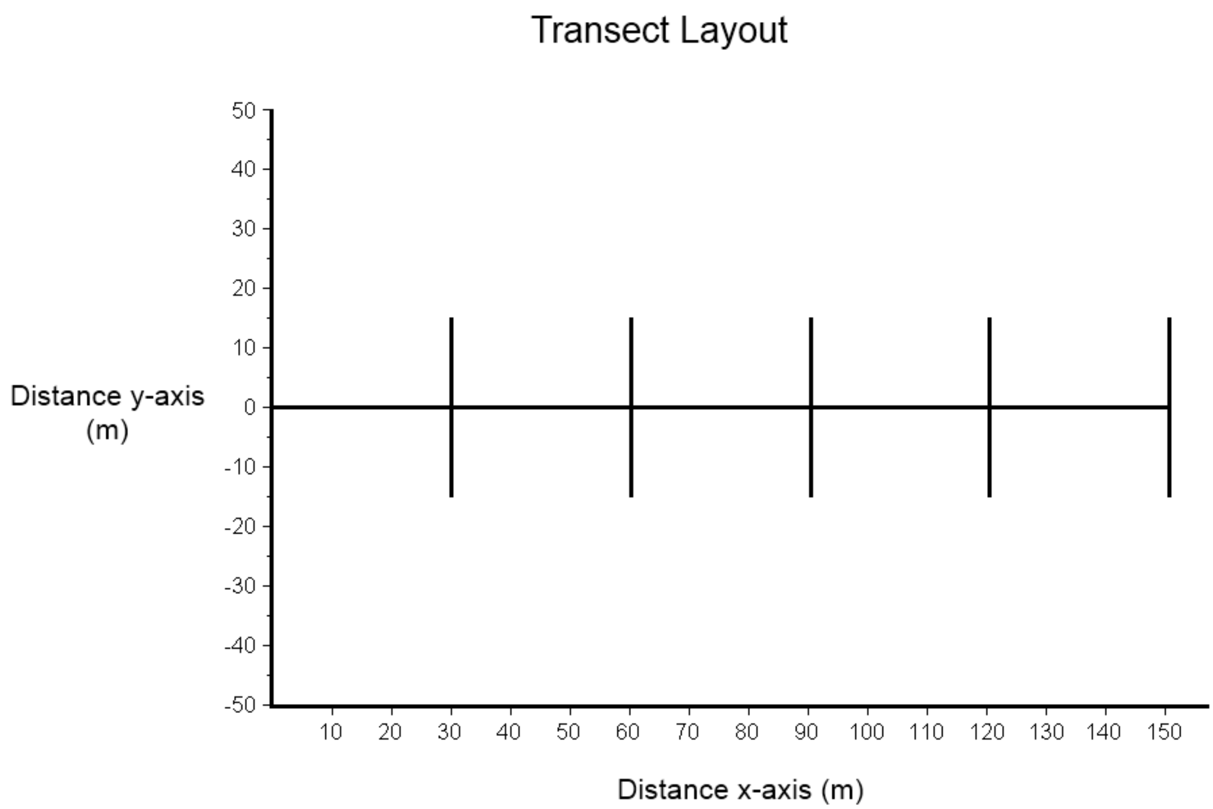

Figure 4. Graphical depiction of transect dimensions used to survey microtopography at Rancho Marino. The x-axis represents length of transect in meters, and the y-axis represents width in meters. Total length covered by transect is 300 meters. Ground surface geometry is recorded every 3 meters (100 nodes in total).

Node sequence proceeds left to right, and top to bottom. For example, 0-m to 27-m on the x-axis contains nodes 1 through 9, and its respective y-axis cross-hash (15-m to -15-m) contains nodes 10 through 20. Nodes 11 through 19 are in the 30-m to 57-m on the a-axis and nodes 20 through 30 are in the following y-axis cross-hash. Nodes 15, 35, 55, 75, and 95 are each located at the intersection between x- and y-axis components of the transect.

2.3 *Survey of Soil Surface*

A model of idealized ground surface geometry (Fig. 5) was designed to guide surveying interpretations along each transect. Factors influencing soil surface morphometries other than the development of pit-and-mound topography could be displacement of soil by root growth or abiotic inherencies in the soil profile (Phillips and Marion, 2006). Surface morphometries were recorded without interpretation to avoid designating any curvature in the ground surface as pit-and-mound topography. The ground surface along each transect is described every 3-m using a numerical array that corresponds to specific points on the model depicted in Figure 5. Convexities and concavities were conservatively recorded. Due to potential error associated with subjective interpretation using this model, nodes that fell on ambiguous ground surfaces (capable of being interpreted as one component or another) were recorded as flat ground ((1) linear). Only clear and distinct concavities and convexities were recorded as such (components 2-5) to avoid over-representing microtopographic curvatures in the soil surface.

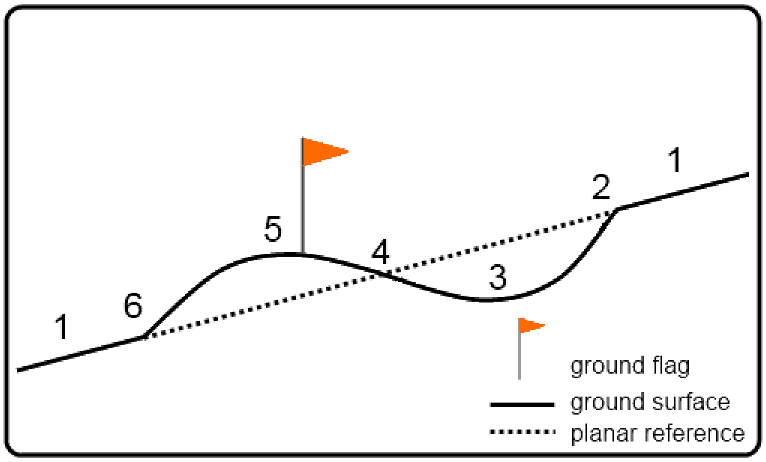

Figure 5. Schematic depiction of idealized ground surface geometry. Geometric features are numerically represented as: (1) linear, (2) linear/concave transition, (3) concave, (4) concave/convex transition, (5) convex, and (6) convex/linear transition. Position (3) is comparable to pit features, and position (5) is comparable to mound features. The flag in position (5) marks where a node might be placed along the transect.

Figure 6. Depiction of idealized ground surface geometry superimposed on the curved ground surface at Rancho Marino.

2.4 *Survey of Tree-Soil Relationships*

In addition to surveying the shape of the soil surface at each node, the geometric positions of nearby trees on the idealized ground surface were recorded. Trees that were positioned within 3-m from a node were recorded. If no tree was present, only the ground surface characteristics were recorded. Tree distributions were mapped for each of the four hill slopes using Google Earth aerial photographs prior to surveying. Individual trees and/or groups of trees were assigned arbitrary numbers. As surveying ensued, trees within proximity to or directly on a node were located on the tree distribution map then investigated to characterize the location of the tree trunk in relation to the ground surface geometry. For example, a node point could be recorded as flat ground (1), but a nearby tree ($\leq$3m away) could be recorded as

growing on a mound component (5) of the ground surface. Use of the idealized ground surface geometry allows for 36 possible scenarios at each node.

Monterey pine often grows in pairs or triplets (Fig. 7) to sustain structural support during the early phases of growth (Canestro, oral comm., 2014). This growing strategy is indicative of wavering root strength during early stages of growth and the limited vertical extent of root biomass in the subsurface beneath Monterey pine trees. Mapping at fine scales is needed to properly account for each individual tree.

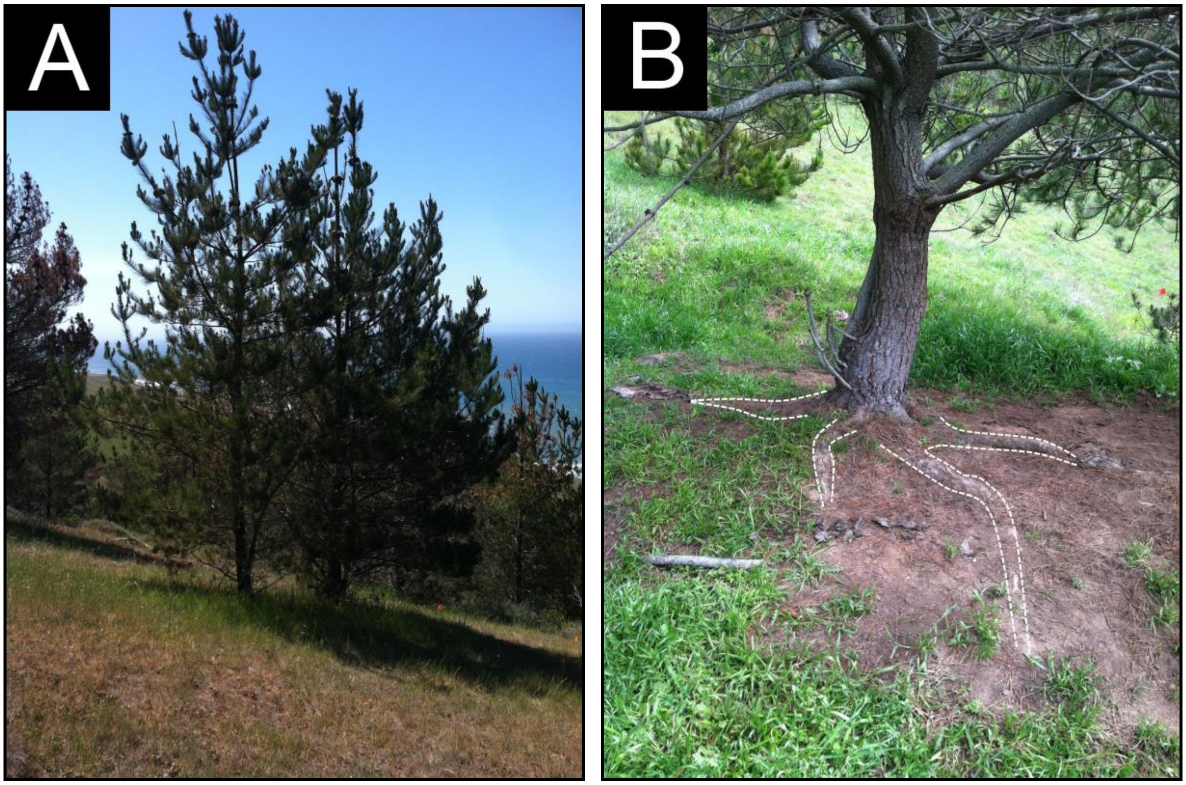

Figure 7. (A) Monterey pine often grows within close proximity of each other for structural support in the subsurface and amongst tree limbs. Trees shown on left are labeled as M.pine #120 on Transect B. **(B)** Lateral roots of M. pine tree breaching the soil surface, demonstrating horizontality of root biomass. Early-life success rates are likely to increase if trees grow in pairs, triplets, etc., rather than individually.

2.5 *Survey of Elevation along Transects*

Changes in elevation along each transect were determined at every node in the x-direction (Fig. 4) by measuring slope using an Abney Level (Fig. 8).

A simple trigonometric equation can be used to calculate changes in elevation between each point by finding the angle between nodes:

Equation 1: $$y = \sin(a) \times h$$

where *y* is the change in elevation, *a* is the angle from horizontal to the top of the surveying staff, and *h* is the distance between each node, which is held constant at 3-m. A total of 50 measurements were taken at each transect.

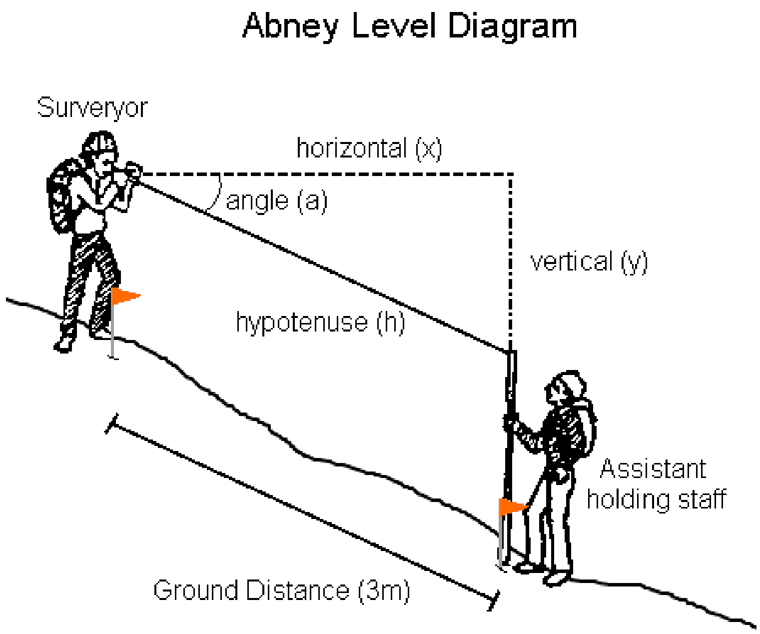

Figure 8. Diagram of geometric values gathered from using the Abney level to compute change in elevation from node to node.

2.6 *Data Collection and Processing*

Data were collected using a table designed to capture the characteristics of each node in a single visit to the range front. Example data are shown in Figure 7 to demonstrate how information was organized and processed.

(1) Node #	**(2)** Ground Surface #	**(3)** Mapped Tree #	**(4)** Tree Location #	**(5)** Abney Level Angle	**(6)** Node Elevation	**(7)** Notes
0	5	-	-		75.00	-
1	1	-	-	14º	75.73	-
2	2	12	5	14º	76.45	tree deceased
3…100	1	45	1	15º	77.23	sapling

Figure 9. Arbitrarily generated example data sheet used to record soil surface characteristics, tree-soil relationships, and changes in elevation. Columns (2) and (4) refer to idealized ground surface geometry depicted in Fig. 5. Column (3) and (4) are left blank if no Monterey pine trees are present within proximity to the node. Column (5) is recorded using the Abney Level and surveying staff, and column (6) is calculated using Equation 1. Column (7) is used to take notes or write descriptions of node qualities not included in the data table.

3. RESULTS

3.1 *Transect Maps*

Transect layouts were carefully mapped along the range front and combined with previously mapped tree distributions. Other features are included for qualitative purposes. Recent aerial photographs (August, 2013) courtesy of Google Earth were used to map tree distributions. Transect layouts and tree distributions were mapped using Paint.net, a free image processing program comparable to Adobe Photoshop. Transect dimensions on each map are distorted due to the projection of two-dimensional figures over the three-dimensional DEM's used in Google Earth, which is a potentially critical problem for geo-spatial accuracy of each map. Transect layout and tree distribution are characteristically accurate, meaning that relative locations of trees and nodes are correct despite error associated with transect projection over the hill-slope DEMs.

Monterey pine locations are marked with green circles. Newly discovered individual trees and tree clusters are labeled the same number as their closest neighbors with an added apostrophe (**'**). Transect path dimensions are mapped with black lines. Chaparral is shown in lime green. Turn-over sites are marked with a light-brown divot pattern.

Transect A

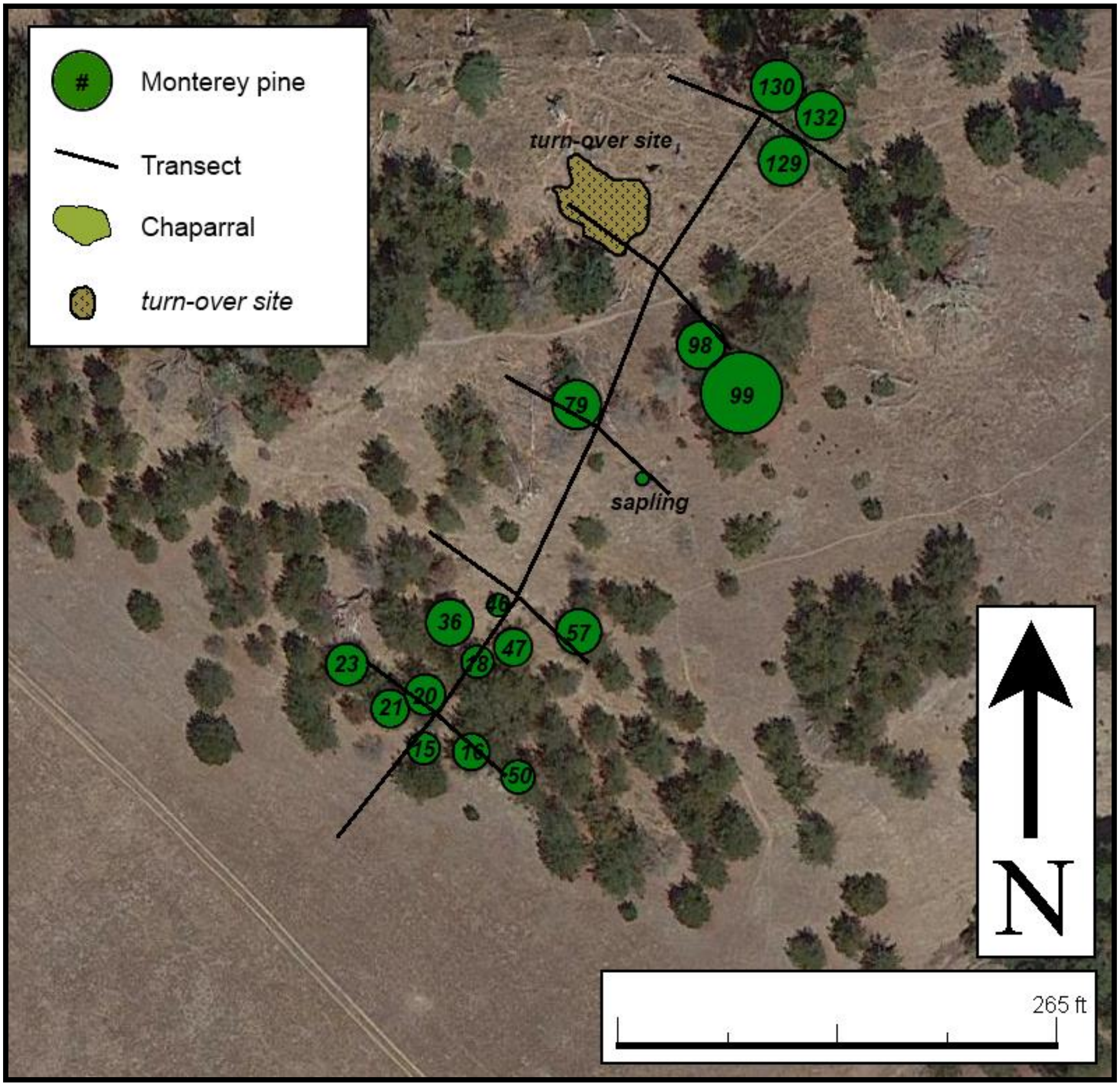

Figure 10. Map of Monterey pine trees encountered along Transect A. In this transect, 18 trees were encountered. Clusters of young to moderately aged pines are present in the lower portions of transect A. Sparsely located, mature trees exist in the upper portions. Turn-over sites are typically composed of snapped trunks, thrown trees, and decomposed and decaying material.

Transect B

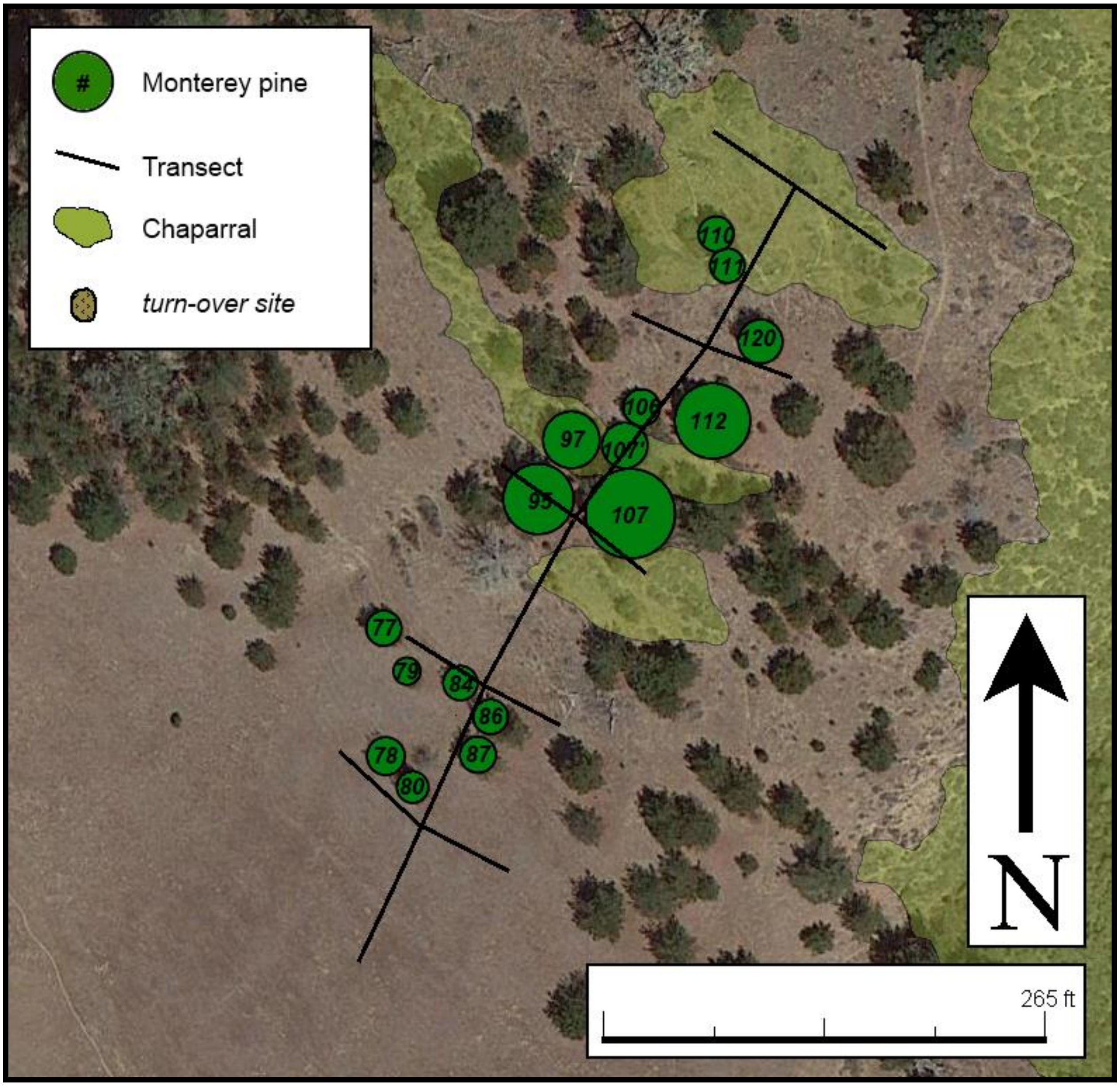

Figure 11. Map of Monterey pine trees encountered along Transect B. In this transect, 16 trees were encountered. Clusters of moderately aged pines are at lower portions of the transect. Clusters of both moderate and mature trees are at middle portions of the transect. Scrub exists on the middle and upper portions of Transect B.

Transect C

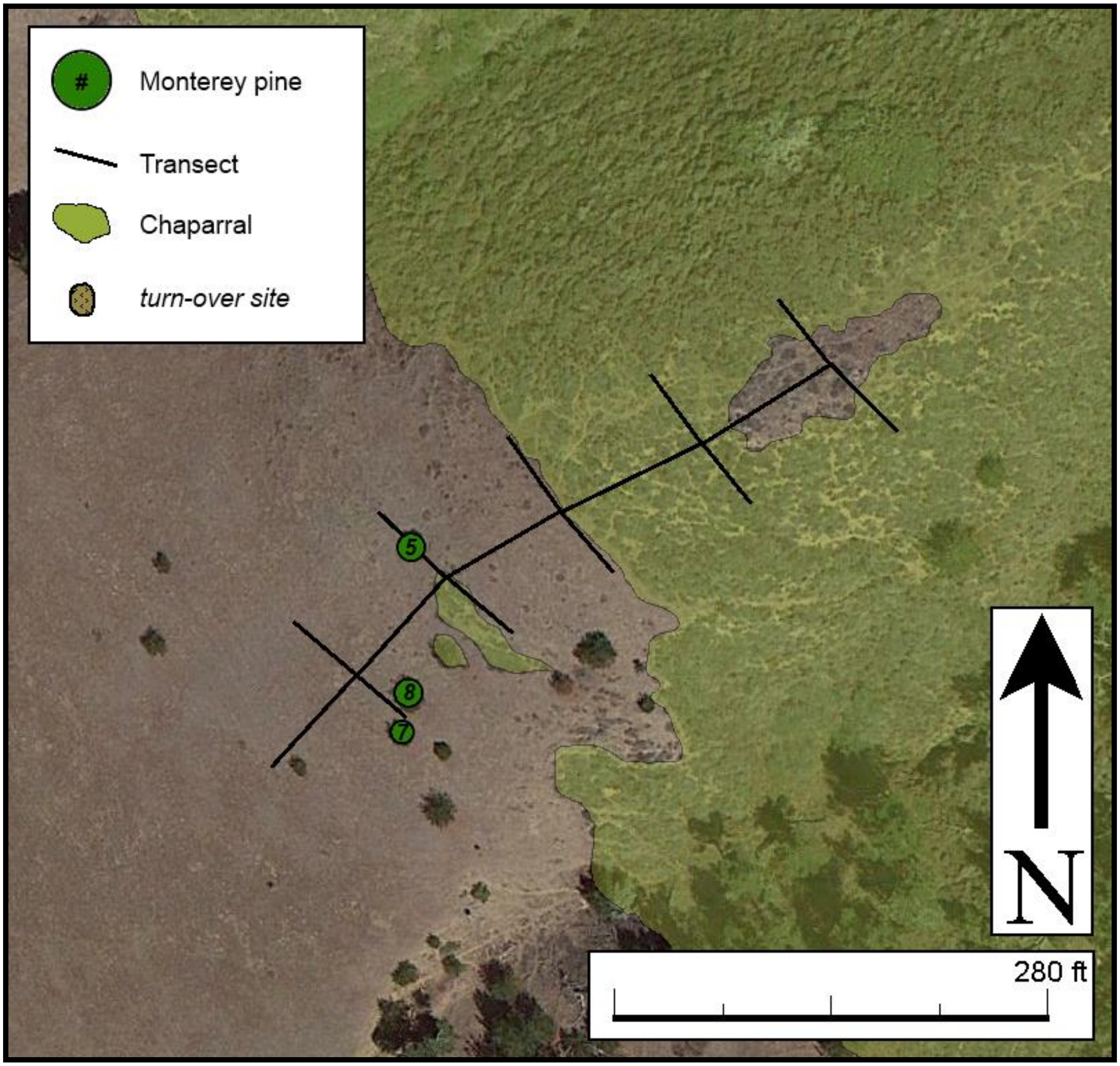

Figure 12. Map of Monterey pine trees encountered along Transect C. In this transect, 3 trees were encountered. Sparsely located young trees are on the lower reaches while scrub dominates the middle and upper portions of Transect C. Coastal scrub becomes more prominent in the upper part of the transect.

Transect D

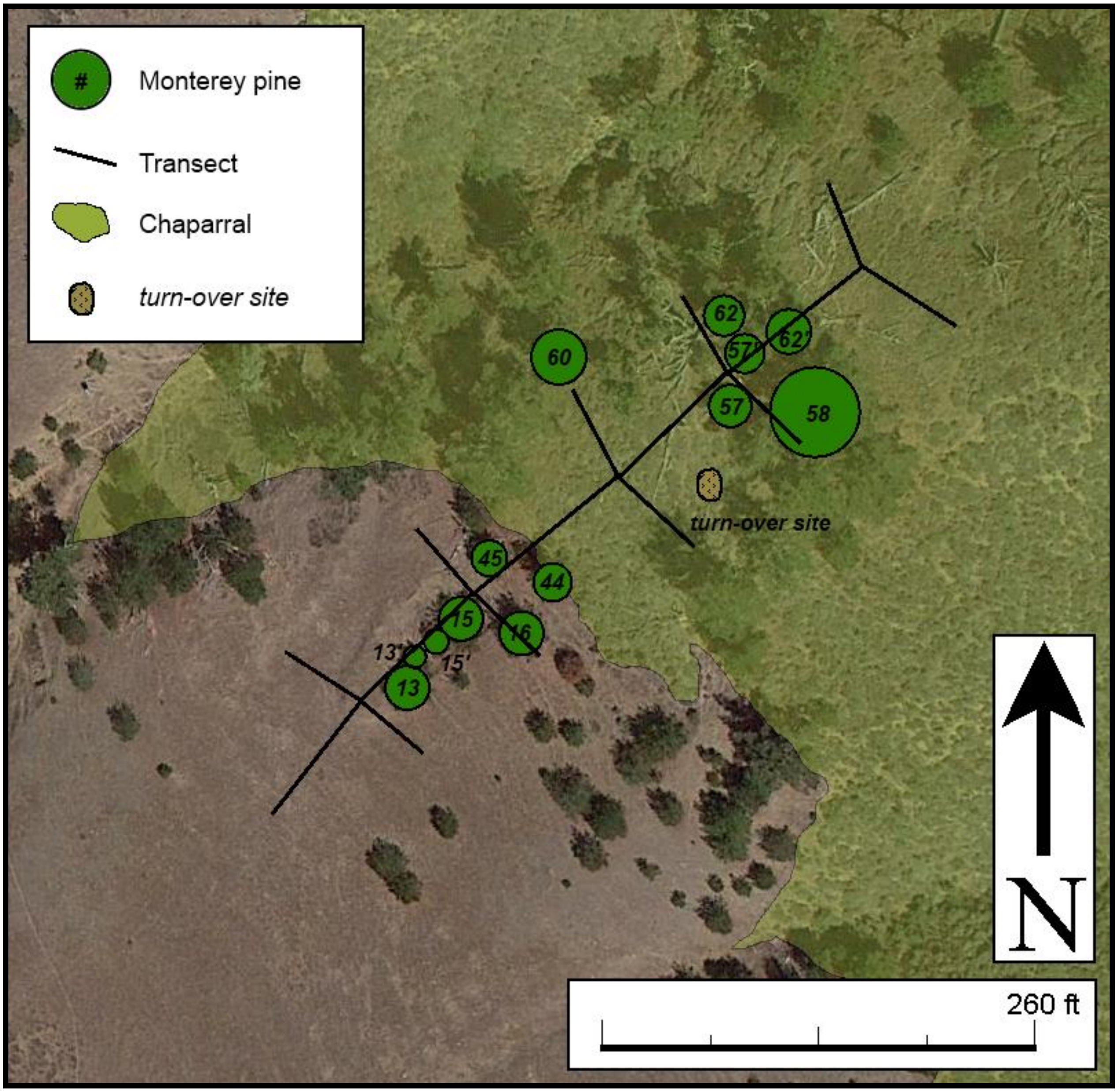

Figure 13. Map of Monterey pine trees encountered along Transect D. In this transect, 13 trees were encountered. Clusters of young to moderately aged trees are present on the land slide component and lower portions of Transect D, while mature trees are present on the upper reaches of Transect D. Scrub dominates the middle to upper reaches of Transect D.

3.2 *Transect Elevation Profiles*

Results from measurements taken in the field underestimate the total change in elevation of Transect A and Transect B. Initial and corrected values were calculated for each transect to demonstrate the shape of the slope and its distortion after elevation values were corrected. Known end-point elevations were found using GPS data collected in-field that were then correlated with topographic maps and Google Earth. For example, the calculated elevation of node #95 on transect A is 168.94 ft, while the known elevation is roughly 205 ft. A calculation was performed to correct the initial values of the profile (Fig. 14) using the difference between the calculated end elevation and the known value:

Equation 2: $$Elev_c = Elev_i + Elev\Delta + [(Elev_t - Elev_f \div 50)] \bullet (node\ \#)$$

Where $Elev_c$ is the corrected elevation, $Elev_i$ is the initial elevation gathered from GPS data, $Elev\Delta$ is the change in elevation from node to node calculated using Equation 1, $Elev_t$ is the true final elevation gathered from GPS data, topographic map data and Google Earth, and $Elev_f$ is the final elevation of node #95 calculated using Equation 1. The difference of the true final elevation and calculated final elevation is divided by 50 because each transect consists of 50 nodes in the x-direction. The *node #* value ranges from 1 through 50.

Error first occurs in the form of reiterative error where inaccurate measurements of changing elevation accumulate as the angles between nodes are recorded. Additional error arises from human error and issues with visibility inside the forest canopy. Error is reduced with more line of sight and practice with the Abney level. Errors are distributed equally in each measurement.

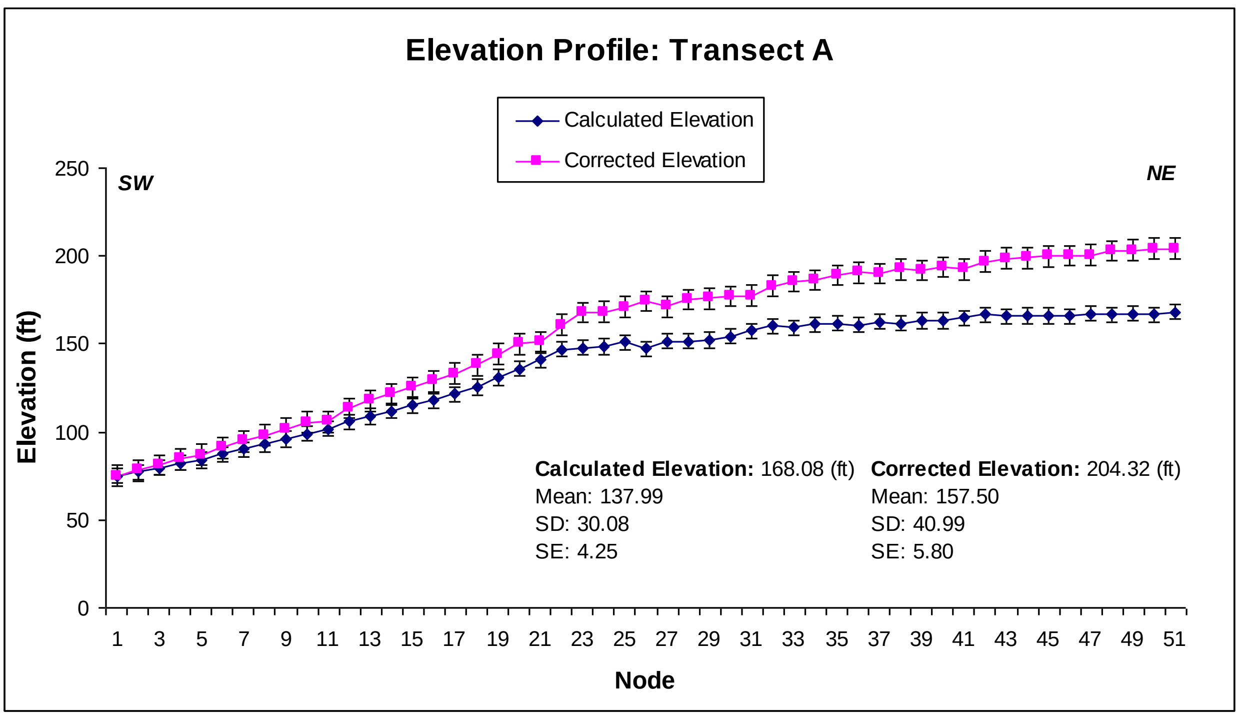

Figure 14. Elevation profile for Transect A showing original calculated values with circular nodes and corrected values with rectangular nodes. Beginning elevation is 75-ft. Distance between nodes is 3-m. Percent error for the final calculated elevation is 17.7%.

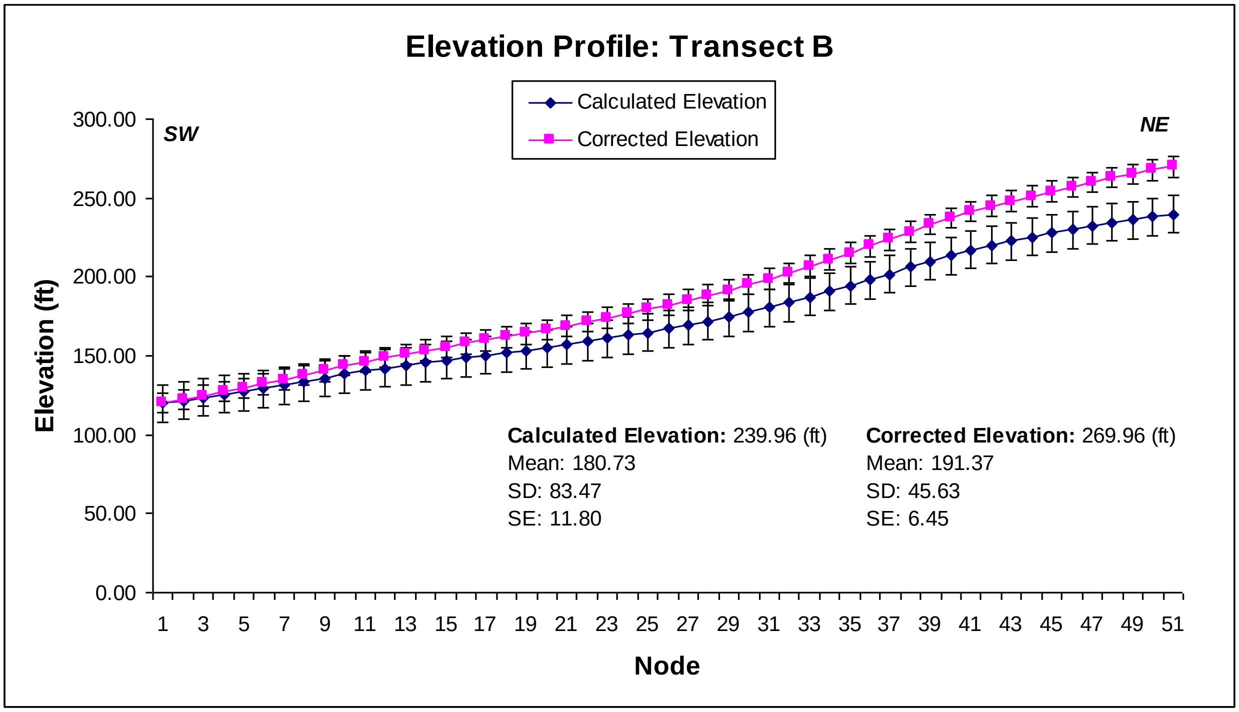

Figure 15. Elevation profile for Transect B showing original calculated values with circular nodes and corrected values with rectangular nodes. Beginning elevation is 120-ft. Distance between nodes is 3-m. Percent error for the final calculated elevation is 11.1%.

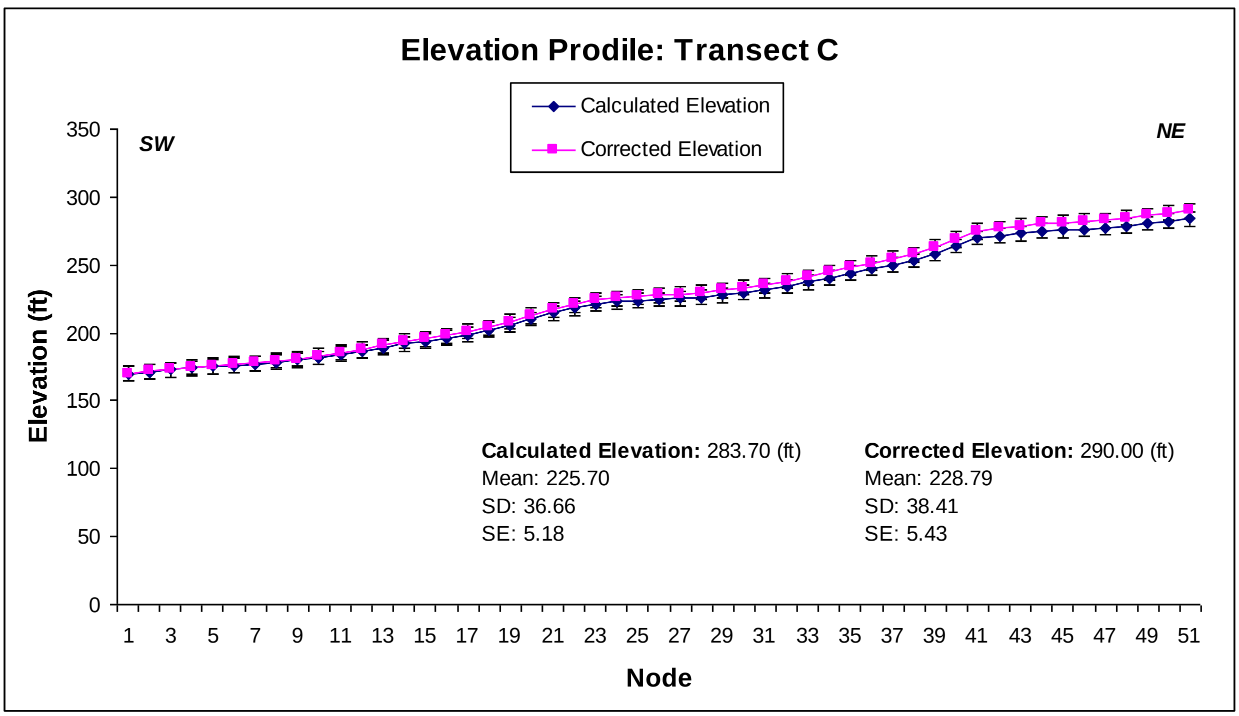

Figure 16. Elevation profile for Transect C showing original calculated values with circular nodes and corrected values with rectangular nodes. Beginning elevation is 170-ft. Distance between nodes is 3-m. Percent error for the final calculated elevation is 2.2%.

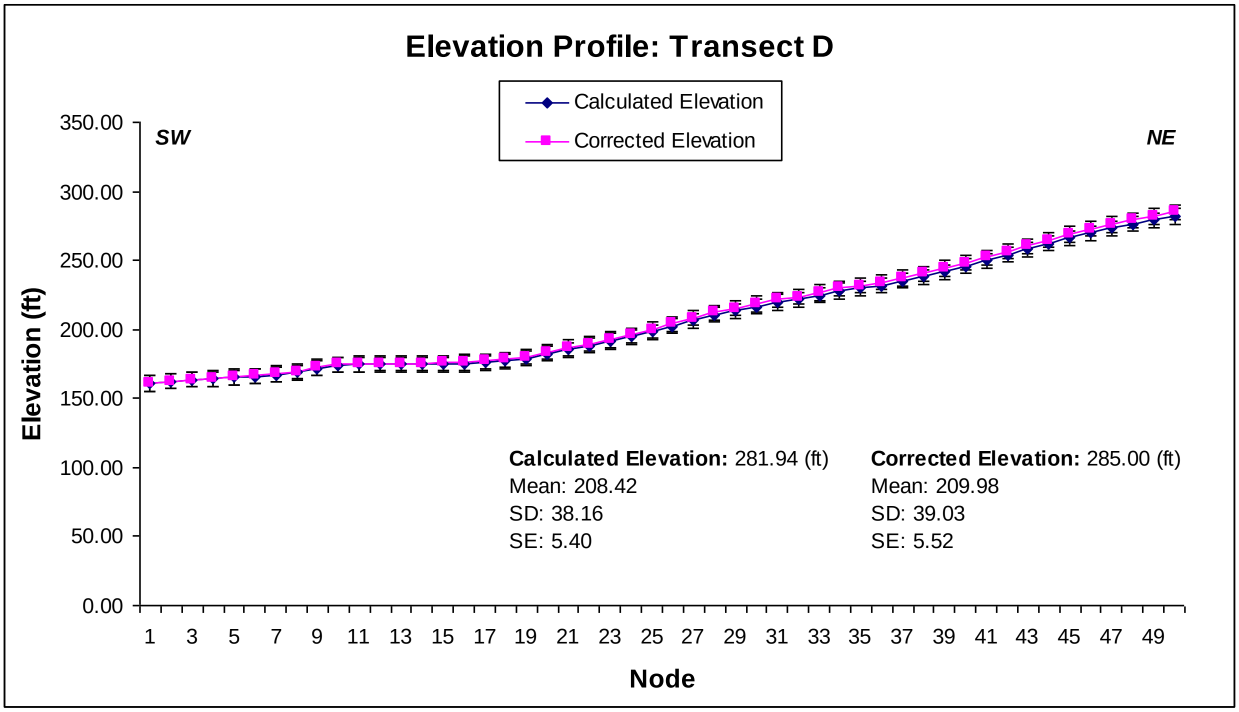

Figure 17. Elevation profile for Transect D showing original calculated values with circular nodes and corrected values with rectangular nodes. Beginning elevation is 160-ft. Distance between nodes is 3-m. Percent error for the final calculated elevation is 1.1%.

3.3 *Quantification of Microtopography*

Microtopography data show significant variation of ground surface geometry throughout the study sites. The vast majority (86%) of surveyed ground was found to be flat, or linear. This is due to sampling methodology which was, again, meant to conservatively estimate curved portions of the ground surface and avoid over-estimating the presence of non-linear ground surfaces. A significant portion (10.5%) of the ground surface was recorded as the convex component, or as the convex-to-linear transition component. The remaining 3.5% were recorded as the 2, 3, and 4 components, or the linear-to-concave transition, the concave component, and concave-to-convex transition respectively.

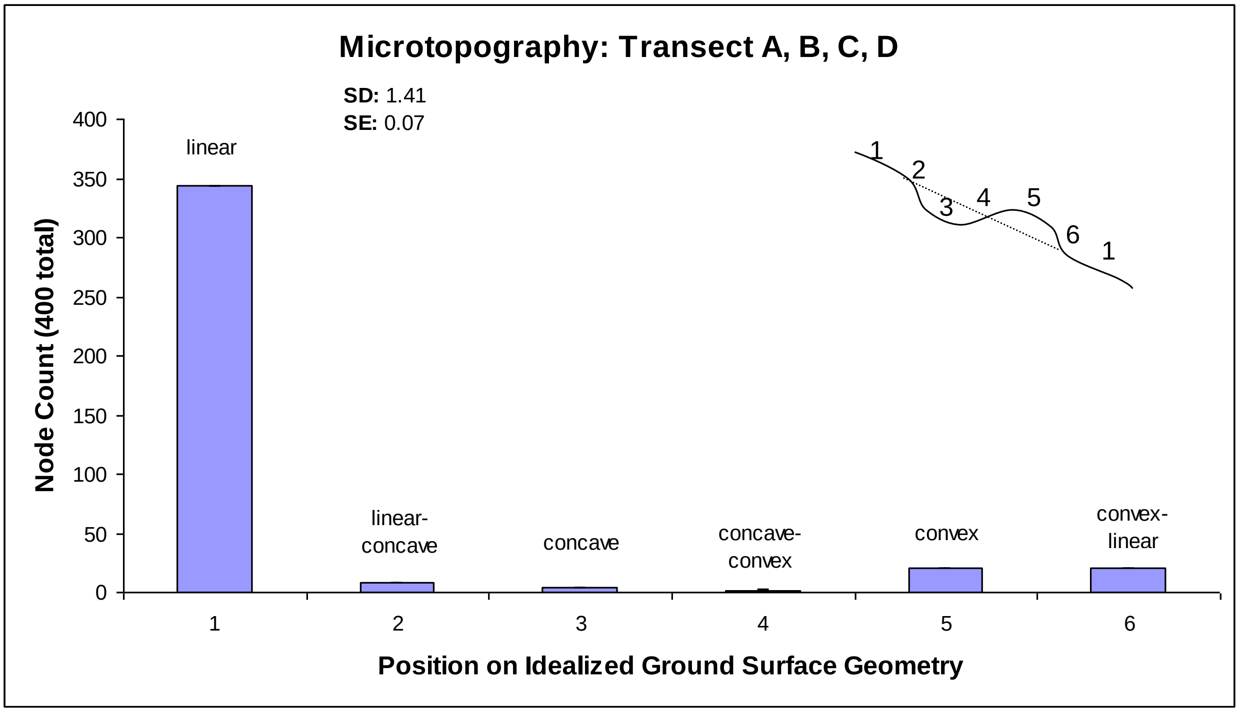

Figure 18. Distribution of idealized ground surface geometric components along Transects A, B, C, and D. Total number of samples = 400.

Table 1 Total number of nodes recorded as geometric components 1 through 6

	(1) linear	(2) linear-concave	(3) concave	(4) concave-convex	(5) convex	(6) convex-linear
# of nodes	344	8	4	2	21	21

3.4 *Tree-Soil Interface*

Tree-soil relationship data show significant variation of tree trunk positioning along the curvature of ground surfaces throughout the study sites. Despite linear ground surfaces dominating in the survey of microtopographic features (86%), only slightly more than half (54%) of surveyed trees were found on flat or linear ground. Trees that were found on convex and convex-to-linear components comprises almost half (44%) of the total amount of trees that were encountered. The remaining 2% of trees were found at the linear-to-concave transition. No trees were found at the concave and concave-to-convex transition components.

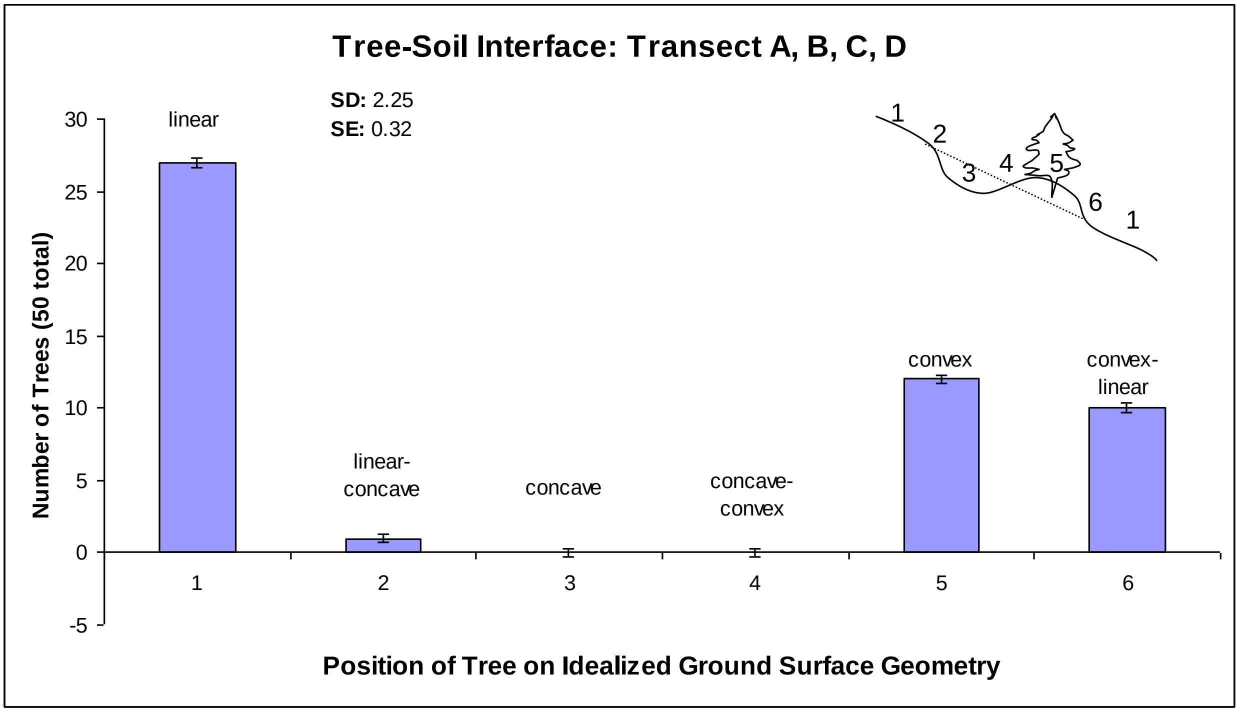

Figure 19. Distribution of Monterey pine positioning within idealized ground surface geometric components along Transects A, B, C, and D. Total number of samples = 50.

Table 2 Total number of trees recorded on geometric components 1 through 6

	(1) linear	(2) linear-concave	(3) concave	(4) concave-convex	(5) convex	(6) convex-linear
# of trees	27	1	0	0	12	10

4. DISCUSSION

4.1 *Elevation Profiles*

The results of this project are indecisive regarding use of the Abney level to accurately quantify slight changes in elevation through rigorous sampling. The high percent error associated with Transects A and B (17.7% and 11.1%) and low percent error associated with Transects C and D (1.1% and 2.2%) leaves us to ponder whether extended practice with the surveying instruments is needed to yield precise measurements, or if more effective methods exist that might yield more precise data.

*There are extensive amounts of LIDAR data for the central coast available online through the GIS Resources link on the Cal Poly Library website.

4.2 *Microtopography*

The vast majority (86%) of ground surface surveyed during this project was linear in shape. However, a significant portion (10.5%) of the ground remains as non-linear surfaces. The high occurrence of linear surfaces is due to conservative measurement of convex and concave components. The adapted method from Kabrick *et al.* (1997) successfully identified microtopographic variations in the ground at the 3-meter length scale, building a case for the presence of a complex ground surface that large scale mapping does not fully characterize. Additional testing of this method along other hill-slopes at Rancho Marino, namely the southern and northern most reaches of the reserve, will serve to either support or reject the findings in this project.

4.3 *Tree-soil Relationships*

An apparent dichotomy of growing preference is shown by the Monterey pines. A slight majority (54%) was recorded growing on linear surfaces while a combined value of 22 trees (44%) were recorded growing on convex and convex-to-linear surfaces. Astonishingly, only 1 tree (2%) was recorded on the linear-to-concave component, and zero trees (0%) were found growing on concave and concave-to-convex components. Growing preferences may depend on whether the tree is growing in a cluster or individually, the slope on which the tree is growing, location on either the north or south facing slope, available nutrients, and a multitude of other factors that influence growing preferences (Douglas 1966).

It is possible that many trees grow on convexities to escape anaerobic environments created by water pooling into the subsurface of pits, causing damage to root systems. Additionally, soil substrates may be looser and more aerated in mounds than soil found in linear and concave components. Soil pit excavations and other ground penetrating methods can be used to investigate nuances in soil morphology and character between sites of varying relief and vegetation.

4.4 *Biological Alteration of Microtopography and Vegetative Responses*

It is generally accepted that trees play a first-order role in soil formation through hydrologic facilitation, mechanical alteration of the substrate, and biogeochemical processes (Roering *et al.,* 2010; Phillips and Marion, 2006; Thompson *et al.,* 2010). Mechanical alteration of soil by *Pinus radiata* at Rancho Marino manifests in the form of “pit-and-mound” topography

– a widely recognized phenomenon amongst researchers investigating the effects of trees on soil formation and surface alteration.

Pit-and-mound topography (Fig. 20) is typically characterized by meter scale concavities and convexities in the soil surface formed by the interplay between trees and soil (Kabrick *et al.,* 1997). This process, known as “tree-throw”, is achieved by trees with a substantial root biomass being uprooted and overturned during excessive shaking from earthquakes, high winds, or storm events.

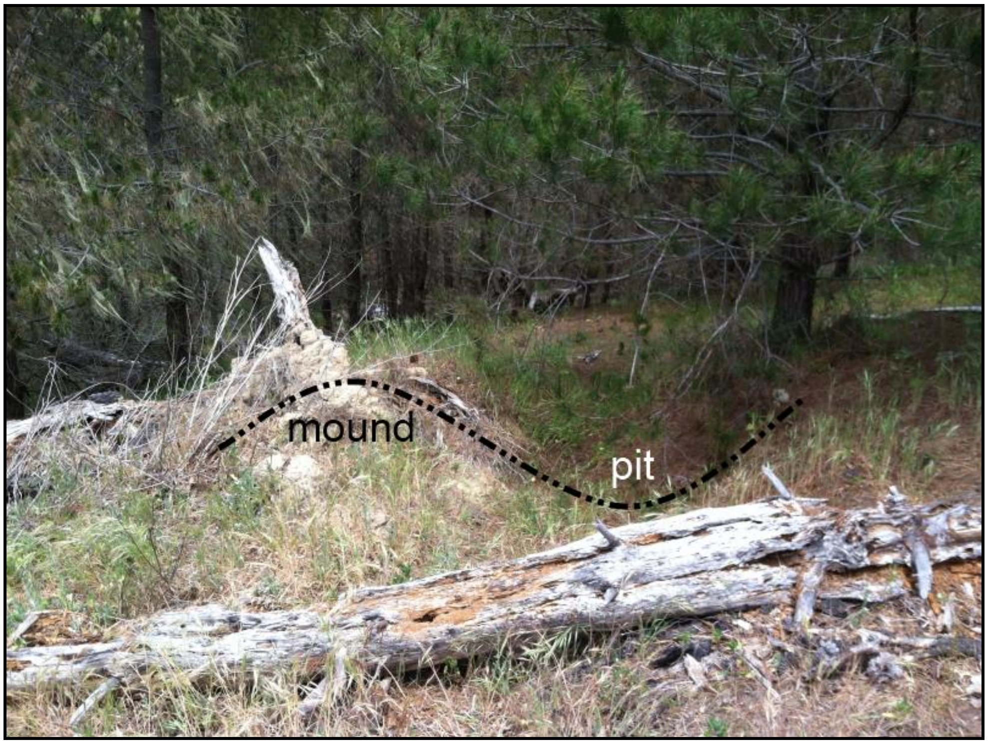

Figure 20. Typical pit-and-mound feature commonly found at or near tree-throw sites throughout Rancho Marino.

Soil and rock fragments integrated into the root mass during growth of the trees are extricated during tree throw. Saprock materials are then subject to further weathering and erosion, gradually breaking down with detritus and taking on the traits of pit-and-mound topography. It is suspected that the soil surface at Rancho Marino has been extensively altered by the biological processes of Monterey pine. An example of this continuous process occurring was found at Transect A and D (Fig. 21).

The recent tree-throw site (Fig. 21) demonstrates how trees are able to accumulate rock fragments and soil within their root-mass, and upon falling over, exhume the material and leave a considerably sized depression. Three concepts are at play: 1) the extrication of subsurface material that is subject to further weathering and erosion, thereby speeding up the pedogenic process; 2) alteration of the shape of the soil surface through mechanical working from tree-throw, and; 3) vegetative responses to mechanical alteration of the soil surface and subsurface.

This process also appears to directly influence competition between plant-functional-types at Rancho Marino. The turn-over site shown in Figure 21 at Transect D (see Fig. 13 for location) is compelling evidence of chaparral invading the growing site of a Monterey pine directly following its turn over. Thus, Monterey pine succession is shown to be a self-influencing process in which many trees establish on biologically altered components of soil

surfaces. This process can be self arresting, where formation of pit-and-mound topography inhibits local Monterey pine trees from effectively growing to mature ages. Alternatively, the bioturbation process may be self enhancing, allowing more and more trees to colonize areas that have been worked by tree turn-over and fertilized by decaying tree matter. More spatial-temporal data is needed to conclude whether Monterey pine encroachment along the range front at Rancho Marino will increase, decrease, or remain constant.

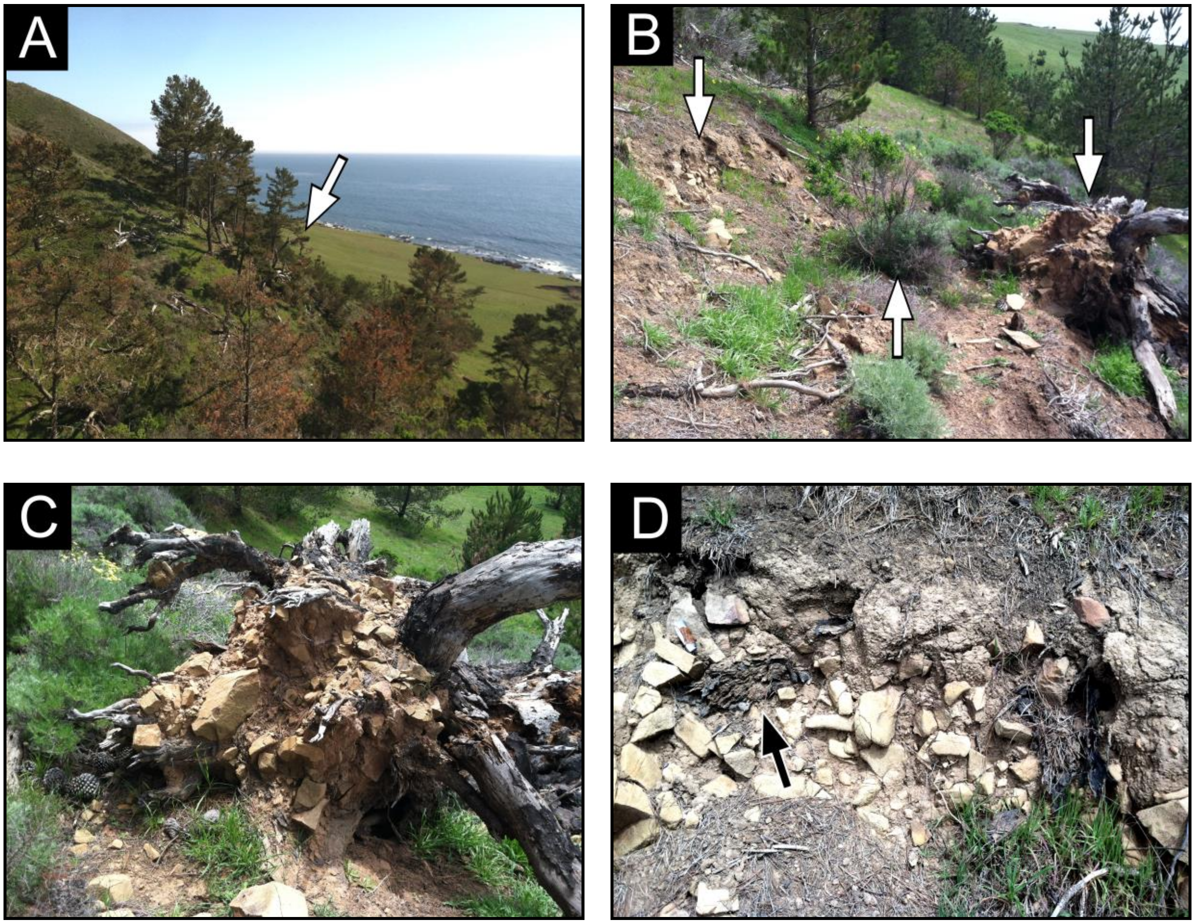

Figure 21. (A) Photo of hill slope D. Note the white arrow pointing to the area of focus in the other three photos. **(B)** Photo of recent tree-throw event. Far-right arrow pointing to overturned Monterey pine tree, middle arrow pointing to coyote bush, and far-left arrow pointing to semi-recently exposed soil sub-surface. **(C)** Photo of extricated rock fragments within root-soil matrix of overturned Monterey pine. **(D)** Photo of sub-surface exposed after upheaval of root-mass. Arrow is pointing to remnant root within soil matrix. Biological alteration of the soil subsurface is apparent

4.5 *Possible Implications and Further Questions*

In a previous study, Roering *et al.* 2010 quantified the curvature of the ground surface at multiple scales using LIDAR data from the Oregon Coast Ranges. They found that curvature values increase with decreasing scale using a calculation known as the interquartile range (IQR) of curvature. The scaling break between ridge-valley terrain and pit-mound features found in Oregon may also be present at Rancho Marino. Investigating this relationship along

the Monterey pine-coastal scrub gradient has the potential to provide a wealth of information on the influence of vegetation on ground morphometry along the range front.

The influence of vegetation extends to sediment supply of an eroding area in the form of hydrologic facilitation, directly altering sedimentological processes (Boer and Puigdefabregas, 2005). Extrication of soil and rock fragments during tree-throw may be a significant source of sediment delivered to coastal alluvial fans at Rancho Marino. Monterey pine may play a first-order role in the sedimentology of the upper most and surficial deposits of the record, and depending on how long it has been growing in Cambria, may have influenced the supply of sediment through longer time scales.

The spatial character and density of different plant species throughout the grassland-forest-chaparral continuum at Rancho Marino may also directly influence soil loss rates (Boer and Puigdefabregas, 2005). It may be possible to quantify or empirically document the influences of biotic and abiotic inputs on soil production.

A) **B)**

Figure 22. Rock fragments within soil-root matrix from (a) hill-slope D, and (b) hill-slope A. Note the greater degree of weathering and integration of rock fragments in (b) versus freshly extricated rock fragments in (a).

Figure 23. Road cut exposure of upper 3 feet of alluvial fan material of hill slope D. Dashed line demarcates rock fragments within darker, clay-rich material overlying lighter, silty material with absence of rock fragments. The presence of rock fragments and fine soil particles may reflect recent colonization of Monterey pine stands and ensuing extrication of materials, allowing the material to become included in debris flows.

Broad similarities in the content of material uprooted by tree-throw and sediment exposed in road cuts of respective hill-slopes is demonstrated in Figures 22 and 23. Rock fragments exposed in root-masses on Hill-slope A appear to be highly weathered and more effectively integrated into the surrounding mineral soil. Rock fragments exposed in root-masses of Hill-slope D appear to be freshly removed from the local bedrock, and fall easily out of the root-soil matrix. A reflection of this is seen in the road cut exposures, in which the exposure near Transect A is absent of rock fragments and the exposure near Transect D bears an abundance of angular rock fragments. Further investigation of this relationship may serve to support or reject the notion of biogenically driven sedimentological processes manifesting in Holocene deposits.

5. CONCLUSIONS

In conclusion, a complex ground surface morphometry exists at Rancho Marino on scales smaller than most soil survey maps characterize. Monterey pines were found to grow equally on linear and convex components of the soil surface. Survey of elevational change along each transect was inconclusive due to a high degree of error associated with line of sight issues and cumulative error from using a datum elevation. The presence of pit-and-mound topography and tree-throw continually affects colonization of Monterey pine along the range front. Long-term dynamics may be at play between the soils, sedimentological processes, forest history, and landscape evolution. Further research is needed to elaborate on the finer points of biological, pedological, and geomorphological interaction at Rancho Marino.

6. REFERENCES

Boer, M., and Puigdefabregas, J., 2005. Effects of spatially structured vegetation patterns on hillslope erosion in a semiarid Mediterranean environment: a simulation study. Earth Surface Processes and Landforms, v.30, pp.149-167.

Douglas, R. F., 1966. Silivicultural characteristics of Monterey pine, USFS Research Paper, PSW 31, pp.1-16.

Kabrick, J. M., Meyers, N. L., McSkweeney, K., 1997. Comparison of sampling methods for estimating pit and mound microtopography. Soil Science Society of America Journal, v. 61, Issue 5, pp. 1423-1427.

O'Farrell, C. R., Heimsath, A. M., Kaste, J. M., 2007. Quantifying hillslope erosion rates and processes for a coastal California landscape over varying timescales. Earth Surface Processes and Landforms, v.32, pp.544-560.

Phillips, J., and Marion, D. A., 2006. Biomechanical effects of trees on soil and regolith: beyond tree throw. Annals of the Association of American Geographers, v.92(2), pp.233-247.

Roering, J. J., Marshall, J., Booth, A. M., Mort, M., Jin, Q., 2010. Evidence for biotic controls on tropography and soil production. Earth and Planetary Science Letters. v. 298, pp. 183-190.

Stokes, M., and Garcia, A. F., 2009. Late Quaternary landscape development along the Rancho Marino coastal range front (South-central Pacific Coast Ranges, California, USA). Journal of Quaternary Science, v.24(7), pp.728-746.

Thompson, S. E., Katul, G. G., Porporato, A., 2010. Role of microtopography in rainfall-runoff partitioning: an analysis using idealized geometry. Water Resources Research, v.46, W07520, doi:1029/2009WR008835

APPENDIX

i. Microtopography and Monterey pine Data

Transect A

Node #	Microtopography	Monterey pine?	Location of Tree
0			
1	6		
2	1		
3	6		
4	2		
5	1		
6	1		
7	3		
8	6	15	5
9	2		
10	6	23	6
11	6		
12	2	21	6
13	1		
14	1	20	2
15	1		
16	1		
17	6	16	6
18	3	16	6
19	2		
20	1	50	5
21	1		
22	1		
23	1		
24	4		
25	6	18	6
26	5	36	5
27	6		
28	6		
29	1	46	6
30	4		
31	6		
32	1		
33	1		
34	1		
35	1		
36	1		
37	1		
38	1		
39	6	57	6
40	6		
41	1		
42	1		
43	1		

44	1		
45	1		
46	6		
47	1		
48	6		
49	6		
50	1		
51	1		
52	6		
53	6		
54	6	79	5
55	1		
56	1		
57	1		
58	1		
59	1	sapling	1
60	1		
61	2		
62	1		
63	1		
64	1		
65	1		
66	1		
67	6		
68	1		
69	1		
70	1		
71	1		
72	1		
73	1		
74	1		
75	1		
76	1		
77	1		
78	1		
79	1	98	1
80	1	99	1
81	1		
82	1		
83	1		
84	1		
85	1		
86	1		
87	1		
88	1		
89	1		
90	1		
91	1		
92	1		
93	1		
94	1		

95	1	130	1
96	1		
97	1	129	1
98	1	132	1
99	1		
100	1		

Transect B

Node #	Microtopography	Monterey pine?	Location of Tree
0	1		
1	1		
2	1		
3	1		
4	1		
5	5		
6	1		
7	1		
8	1		
9	1		
10	1		
11	1		
12	1	78	6
13	1		
14	1	80	1
15	2		
16	1		
17	1		
18	1		
19	1		
20	1		
21	1		
22	1		
23	1		
24	1		
25	1		
26	1	87	1
27	1		
28	1	86	1
29	1		
30	1	77	1
31	1		
32	1	79	1
33	1		
34	1	84	1
35	1		
36	1		
37	1		
38	1		
39	1		

40	1		
41	1		
42	1		
43	1		
44	1		
45	1		
46	1		
47	1		
48	1		
49	1		
50	6		
51	6		
52	1		
53	1	95	5
54	1		
55	1		
56	1		
57	1		
58	1	107	5
59	1		
60	1		
61	1		
62	1		
63	1		
64	1	97	6
65	5	107'	5
66	1	106	1
67	1	112	1
68	1		
69	1		
70	1		
71	1		
72	1		
73	1		
74	1		
75	1		
76	1		
77	1	120	1
78	1		
79	1		
80	1		
81	1		
82	1		
83	1		
84	1		
85	1	111	1
86	1	110	5
87	3		
88	2		
89	1		
90	3		

91	1		
92	1		
93	1		
94	1		
95	1		
96	1		
97	1		
98	1		
99	1		
100	2		

Transect C

Node #	Microtopography	Monterey pine?	Location of Tree
0	1		
1	1		
2	1		
3	1		
4	1		
5	1		
6	1		
7	1		
8	1		
9	1		
10	1		
11	1		
12	1		
13	1		
14	1		
15	1		
16	1		
17	1		
18	1		
19	1	7	1
20	1	8	1
21	1		
22	1		
23	1		
24	1		
25	1		
26	1		
27	1		
28	1		
29	1		
30	1		
31	1		
32	1		
33	1		
34	1		
35	1		
36	1		

37	1		
38	1		
39	5		
40	1		
41	1		
42	1		
43	1	5	1
44	1		
45	5		
46	1		
47	1		
48	1		
49	1		
50	1		
51	1		
52	1		
53	1		
54	1		
55	1		
56	1		
57	1		
58	1		
59	1		
60	1		
61	1		
62	1		
63	1		
64	1		
65	1		
66	1		
67	1		
68	1		
69	1		
70	1		
71	1		
72	1		
73	1		
74	1		
75	1		
76	1		
77	1		
78	1		
79	1		
80	1		
81	1		
82	1		
83	1		
84	1		
85	1		
86	1		
87	1		

88	1		
89	1		
90	1		
91	1		
92	1		
93	1		
94	1		
95	1		
96	1		
97	1		
98	1		
99	1		
100	1		

Transect D

Node #	Microtopography	Monterey pine?	Location of Tree
0	1		
1	1		
2	1		
3	1		
4	1		
5	1		
6	1		
7	1		
8	5		
9	5		
10	1		
11	1		
12	1		
13	5		
14	6		
15	6		
16	6		
17	5		
18	1		
19	1		
20	1		
21	1		
22	1		
23	1	13	1
24	1	13'	1
25	1	15'	1
26	5	15	1
27	5		
28	6		
29	5		
30	1		
31	1		
32	1		
33	1		

34	1		
35	1		
36	1		
37	1		
38	1	16	1
39	1		
40	1		
41	1		
42	1	45	5
43	5		
44	5	44	5
45	1		
46	1		
47	5		
48	5		
49	6		
50	1		
51	1	60	6
52	1		
53	1		
54	1		
55	1		
56	1		
57	1		
58	1		
59	1		
60	1		
61	1		
62	1		
63	1		
64	1		
65	1		
66	1		
67	1		
68	1		
69	1	57	5
70	1		
71	1		
72	1	62	1
73	1		
74	1		
75	1		
76	1		
77	1		
78	1		
79	1	58	1
80	1		
81	1	57'	1
82	1		
83	1		
84	1	62'	5

85	1		
86	1		
87	1		
88	1		
89	1		
90	1		
91	1		
92	1		
93	1		
94	1		
95	1		
96	1		
97	1		
98	1		
99	1		
100	1		

ii. Rancho Marino Plant List

Genus_Species	Common Name	Division
Achillea millefolium	White yarrow	Angiosperm
Adiantum jordanii	California Maiden-Hair	Ferns & Allies
Agoseris sp.		Angiosperm
Agrostis hallii	Halls Bent Grass	Angiosperm
Agrostis pallens	Woodland Bent Grass	Angiosperm
Agrostis viridis	Water Bent Grass	Angiosperm
Aira caryophyllea	Hair grass	Angiosperm
Alcea rosea	Hollyhock	Angiosperm
Amsinckia menziesii	Common fiddleneck	Angiosperm
Anagallis arvensis	Pimpernel	Angiosperm
Anagallis minimus	Chaffweed	Angiosperm
Armeria maritima	Thrift	Angiosperm
Artemisia californica	California Sagebrush	Angiosperm
Astragalus nuttallii	Gray Locoweed	
Avena barbata	Slender wild oats	Angiosperm
Avena fatua	Common Wild Oats	Angiosperm
Baccharis douglasii	Douglas' baccharis	Angiosperm
Baccharis pilularis	Coyote Brush	Angiosperm
Brachypodium distachyon	False Brome-Grass	Angiosperm
Brassica geniculata	Summer Mustard	Angiosperm
Brassica nigra	Black Mustard	Angiosperm
Briza maxima	Rattlesnake Grass	Angiosperm
Briza minor	Little Rattlesnake Grass	Angiosperm
Bromus carinatus	California Brome Grass	Angiosperm

Bromus diandrus	Ripgut Brome grass	Angiosperm
Bromus hordeaceus	Soft Chess Brome Grass	Angiosperm
Bromus maritimus	Maritime California Brome Grass	Angiosperm
Cakile maritima	Sea Rocket	Angiosperm
Calandrinia ciliata	Redmaids	Angiosperm
Calochortus albus	White Globe Lily	Angiosperm
Calystegia macrostegia	Coast Morning Glory	Angiosperm
Carduus pycnocephalus	Italian Thistle	Angiosperm
Carex hartfordii	Sedge	Angiosperm
Carex sp.	Sedge	Angiosperm
Carpobrotus chilensis	Iceplant, Sea Fig, Fig-Marigold	Angiosperm
Carpobrotus edulis	Iceplant, Sea Fig, Fig-Marigold	Angiosperm
Castilleja affinis	Common Indian Paintbrush	Angiosperm
Castilleja densiflora	Obispo owl clover	Angiosperm
Castilleja exserta	Purple owl clover	Angiosperm
Cerastium sp.	Mouse-eared Chickweed	Angiosperm
Chamaesyce ocellata	Valley Spurge	Angiosperm
Genus_Species	**Common Name**	**Division**
Chamomilla suaveolens	Pineapple Weed	Angiosperm
Chasmanthe floribunda	Ethiopian Sand Lilly	Angiosperm
Chlorogalum pomeridianum	Soap Plant	Angiosperm
Cirsium occidentale	Cobweb thislte	Angiosperm
Cirsium vulgare	Bull Thistle	Angiosperm
Clarkia davyi		Angiosperm
Conium maculatum	Poison Hemlock	Angiosperm
Conyza canadensis	Horseweed	Angiosperm
Corethrogyne filaginifolia	California-Aster	Angiosperm
Cyperus eragrostis	Umbrella sedge	Angiosperm
Danthonia californica	Calif. Oatgrass	Angiosperm
Dentaria californica	Milkmaid/toothwort	Angiosperm
Deschampsia danthonioides	Annual Hairgrass	Angiosperm
Dichelostemma capitatum	Blue Dicks	Angiosperm
Distichlis spicata	Salt Grass	Angiosperm
Dudleya sp.		Angiosperm
Eleocharis acicularis	Needle Spikerush	Angiosperm
Eleocharis macrostachya	Common Spike-rush	Angiosperm
Elymus glaucus	Blue Wild Rye	Angiosperm
Epilobium canum	CA fuchsia	Angiosperm
Erigeron glaucus	Seaside Daisy	Angiosperm
Eriogonum parvifolium	Dune Eriogonum	Angiosperm
Eriophyllum staechadifolium	Lizard Tail	Angiosperm
Erodium botrys	Filaree	

Erodium moschatum	White stem filaree	
Eryngium armatum		Angiosperm
Eschscholzia californica	California Poppy	Angiosperm
Euphorbia peplus	Petty Spurge	
Festuca arundinacea	Meadow Fescue	Angiosperm
Festuca californica	California fescue	Angiosperm
Festuca sp.	Fescue Grass	Angiosperm
Filago gallica	Hierba Impia	Angiosperm
Fragaria vesca	California Strawberry	Angiosperm
Fritillaria biflora	Chocolate Lily	Angiosperm
Galium aparine	Common Bedstraw	Angiosperm
Galium californicum	Bedstraw	Angiosperm
Geranium dissectum	Cut-leaf Geranium	
Gnaphalium luteo-album	Weedy Cudweed	Angiosperm
Grindelia stricta	Gumplant	Angiosperm
Hazardia squarrosa	Saw-Toothed GoldenBush	Angiosperm
Hedypnois cretica	Crete weed	Angiosperm
Genus_Species	**Common Name**	**Division**
Helenium puberulum	Sneezeweed	Angiosperm
Hemizonia congesta	Hayfield Tarweed	Angiosperm
Hemizonia corymbosa	Large-flowered coast tarplant	Angiosperm
Heteromeles arbutifolia	Toyon	Angiosperm
Holodiscus discolor	Cream bush	Angiosperm
Hordeum branchyantherum	Meadow barley	Angiosperm
Hordeum marinum	Mediterranean Barley	Angiosperm
Hordeum murinum	Farmer's Foxtail, Foxtail…	Angiosperm
Hypochaeris glabra	Smooth Cats Ears	Angiosperm
Hypochaeris radicata	Rough Cat's-Ear	Angiosperm
Isocoma menziesii	Coastal Isocome	Angiosperm
Juncus bufonius	Toad Rush	Angiosperm
Juncus effusus	Toad Rush	Angiosperm
Juncus occidentalis	Western Rush	Angiosperm
Juncus patens	Salt Rush	Angiosperm
Juncus phaeocephalus	Rush	Angiosperm
Koeleria macrantha	June Grass	Angiosperm
Lathryus Jepson Prairieii	Jepson Prairie’s Pea, Tule Pea	
Lathyrus vestitus	Wild Sweet-Pea	
Lepidium strictum	Peppercress	Angiosperm
Leymus condensatus	Giant Wild Rye	Angiosperm
Leymus triticoides	Creeping Wild Rye	Angiosperm
Lolium multiflorum	Lawn Ryegrass	Angiosperm
Lonicera sp.	Honeysuckle	Angiosperm

Lotus heermannii	Woolly deer-vetch	
Lotus humistratus	Short-poded Lotus	
Lotus scoparius	Deer weed, deer brush	
Lupinus nanus	Sky lupine	
Lupinus succulentus	Arroyo lupine	
Luzula multiflora	Hairy wood rush	Angiosperm
Lythrum hyssopifolium	Wallow Poly	Angiosperm
Madia sativa	Coast tarweed	Angiosperm
Malva nicaeensis	Bull mallow	Angiosperm
Malva parviflora	Cheeseweed	Angiosperm
Medicago polymorpha	Medic	
Melica imperfecta	Onion Grass	Angiosperm
Melilotus indicus	Annual yellow sweetclover	
Mimulus aurantiacus	Northern Sticky Monkeyflower	Angiosperm
Mimulus guttatus	Seep monkey flower	Angiosperm
Nassella pulchra	Purple Needlegrass	Angiosperm
Oxalis albicans	Yellow wood sorrel	Angiosperm
Genus_Species	**Common Name**	**Division**
Oxalis pes-caprae	Bermuda Buttercup, a Sorrel	Angiosperm
Pellaea sp.	Coffee fern	Ferns & Allies
Pennisetum clandestinum	Kikuyu Grass	Angiosperm
Phalaris aquatica	Harding Grass	Angiosperm
Phalaris californica	California canary grass	Angiosperm
Picris echioides	Ox Tongue	Angiosperm
Pinus radiata	Monterey Pine	Gymnosperm
Piperia elongata	Rein orchid	Angiosperm
Plantago erecta	Plantain	Angiosperm
Plantago lanceolata	Ribwort, Plantain	Angiosperm
Plantago major	Common plantain	Angiosperm
Poa annua	Annual Bluegrass	Angiosperm
Polycarpon tetraphyllum	All-seed	Angiosperm
Polygonum arenastrum	Knotweed	Angiosperm
Polypodium glycyrrhiza	Licorice Fern	Ferns & Allies
Polypogon interruptus	Ditch beard grass	Angiosperm
Polypogon monspeliensis	Rabbitfoot Grass	Angiosperm
Quercus agrifolia	CoastLive Oak	
Ranunculus californicus	Buttercup	Angiosperm
Raphanus sativus	Wild radish	Angiosperm
Ribes sanguineum	Pink flowering currant	
Ribes speciosum	Fuchsia-flowered Gooseberry	
Rorippa nasturtium-aquaticum	Water cress	Angiosperm

Rubus ursinus	California blackberry	Angiosperm
Rumex acetosella	Sheep Sorrel	Angiosperm
Rumex conglomeratus	Knotted dock	Angiosperm
Rumex crispus	Curly Dock	Angiosperm
Rumex pulcher	Fiddle Dock	Angiosperm
Salix lasiolepis	Arroyo Willow	Angiosperm
Salvia spathacea	Crimson Sage	Angiosperm
Sanicula arguta	Shining sanicle	Angiosperm
Sanicula crassicaulis	Gambleweed, Sanicle	Angiosperm
Sanicula laciniata	Cutleaf sanicle	Angiosperm
Satureja douglasii	Yerba buena	Angiosperm
Scrophularia californica	Figwort	Angiosperm
Senecio mikanioides	German ivy	Angiosperm
Silene gallica	Windmill pink	Angiosperm
Silybum marianum	Milk Thistle	Angiosperm
Sisymbrium officinale	Hedge mustard	Angiosperm
Sisyrinchium bellum	Blue-Eyed "Grass"	Angiosperm
Solanum douglasii	Douglas Nightshade	Angiosperm
Genus_Species	**Common Name**	**Division**
Soliva sessilis	Soliva	Angiosperm
Sonchus asper	Prickly Sow thistle	Angiosperm
Sonchus oleraceus	Sow thistle	Angiosperm
Spergula arvensis	Corn Spurry	Angiosperm
Spergularia macrotheca	Spergula	Angiosperm
Stachys bullata	Hedge Nettle	Angiosperm
Stellaria media	Chickweed	Angiosperm
Tetragonia tetragonioides	New Zealand Spinach	Angiosperm
Toxicodendron diversilobum	Poison Oak	Angiosperm
Toxicoscordion fremontii	Fremont’s Star-Lily	Angiosperm
Trifolium campestre	Hop clover	
Trifolium fucoitum	Bull Clover	
Trifolium repens	Dutch White Clover	
Trifolium subterraneum	Clover	
Viola pedunculata	Violet, Johnny Jump Up	Angiosperm
Vulpia microstachys	Six week Fescue	Angiosperm
Vulpia myuros	Rattail Fescue	Angiosperm
Zantedeschia aethiopica	Calla-Lily	Angiosperm