Direct Effects of Elevation on Tree Size and Forest Density on Maderas Volcano, Nicaragua

By

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Abstract

The forest visually changes with elevation on Maderas Volcano in Nicaragua. This study investigates the attributes of the forest that change with elevation; by taking measurements of tree's Diameter at Breast Height and Forest Density using the Point Center Quarter method at three different elevation sites. A significant decrease in forest density was found between the low elevation forests and the high elevation forests. The forest gets less dense as elevation increases on Maderas volcano.

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Literature Review

An ecosystem is a functional system that includes an assemblage of interacting organisms and their environment, which acts on them and which they act on (Kimmins, 1997). Understanding this is fundamental to any type of research in any field of environmental science. The concept of an ecosystem is comprised of five major attributes; structure, function, complexity, interaction & interdependence, and temporal change. Structure in this context is referring to the fact that a functional ecosystem is comprised of both an abiotic environment and a biotic community. Both of these categories can be further broken down into a more specific list of factors. For the biotic community will consist of the plant, animal, and microbial community; and the abiotic environment contains both atmospheric and terrestrial factors. Function refers to the ability of an ecosystem to allow for the transfer of energy between the inorganic environment and the organic community. This attribute focuses on the physical-chemical exchange of matter and energy between "members" of the abiotic and the biotic communities. The ability for nutrients to cycle properly throughout a system is crucial to its longevity. Complexity describes the inherent fact that a healthy ecosystem's events are determined by a multitude of different factors. Without the proper knowledge of the structure and function each ecosystem has developed, it becomes very difficult to predict with any degree of certainty. Interaction and Interdependence address the fact that due to the high levels of complexity involved in the interactions of ecological factors means that with a change in just one, a subsequent change in nearly every other factor will occur. In any complex interdependent community this is found to be true. Temporal change is an attribute the deals interlay with time. More specifically the passage of time in relation to the ecosystem. A healthy ecosystem is never static in any way, there is constant movement, whether it be of energy or matter. The principle behind this attribute is that an ecosystem is constantly undergoing change. This "definition" of an ecosystem works well in theory, however when it comes to application it struggles to clearly define important physical attributes such spatial extent. This term of ecosystem does not focus on geographical boundaries of a given system. In order to properly understand what an ecosystem is and how it will respond under certain circumstances, a knowledge of what forces are acting on it must be acquired. These forces are often referred to as factors; these factors are separated into two categories. The first category of factors are known as abiotic. "An abiotic factor is an inorganic chemical or physical factor in the environment." (Montello, 2006) Some examples of abiotic factors include: soil, solar radiation, temperature, precipitation. The other type of factor is what is known as a biotic factor. A biotic factor is a factor that is created by a living think within a given environment which affects other organisms or factors. Some example of biotic factors are: photosynthesis, decomposers, herbivores, carnivores, and omnivores. These factors are constantly interacting with one another and during those interactions they influence one another. An ecosystem is determined by the relationship these factors share with one another. Similarity to understanding an ecosystem, in order to understand what abiotic factors are as a category, a better knowledge of what an abiotic factor is, and in which ways each of them are able to effect the ecosystem they are a part of. Just as the list of factors could be organized into abiotic and biotic, the same can be done with biotic factors. "Abiotic factors can be separated into four subcategories: meteorological, edaphic, topography, hydrological." (Hogan, 2011) Meteorological factors include: temperature, humidity, wind, precipitation, solar radiation. Meteorological factors are factors that are a direct result of the climate the area is exposed to. This group of factors is often responsible for the disastrous events an ecosystem suffers from such as hurricane wind and forest fire sparked from drought. Edaphic factors are factors that relate the soil of an ecosystem. The soil of a healthy ecosystem can often be thought of as the foundation of the food chain. The edaphic factors often directly influence the flora of an area and from the flora herbivores, and carnivores are influenced. Such soil factors include: soil composition, soil granularity, and nutrient content. Edaphic factors effectively showcase the interconnectivity of an ecosystem, the influencing of food chain strength from variables of soil is a good example of this. Topographic factors are factors relate mainly to the geology of an area. These factors include elevation, rock type, and rain water drainage. These factors interact heavily with meteorological factors in the production of a habitat. Elevation plays a large role in the climate of an area, and in term the climate often determines the plant availability and survival rate. The last subcategory of abiotic factors can be defined as hydrologic. These factors are defined by their relationship to the hydrosphere. Some examples of hydrologic factors are water quality, water availability, and water pH. This specific subset of factors integrates into all others through the process known as the water cycle, which carries water into every previously listed subset of factors. The quality and availability of water is a driving force behind some of the most popular and extreme biotic adaptions. An adaptation can be defined as “a mutation or genetic change that helps and organism, such as a plant or animal, survive in its environment” (Rutledge, 2011). The term adaptation is broad in its general definition. One form of adaptation is behavioral adaptation; it refers to a learned action the organism takes to further its survival.

Some examples of behavioral adaptation would be migration patterns of the Grey Whale. The other form of adaptation refers to the physical mutations that occur between generations that alter the physical body of an organism's structure. This is known as a structural adaptation. Some examples of structural adaptions are feathers, or fins. Some of these adaptations are known as exaptations, these are defined as an adaptation developed for one purpose but also used for other purposes. One specific example of this would be feathers which were originally developed to insulate the animal, but were later used in the aiding of flight. Habitat is generally the driving force behind every adaptation. They are usually developed as a direct response to the organism's current environment. "A recent and prominent example of habitat driven adaptation can be found in 19th century Europe where the peppered moth had originally been mostly cream colored, but during the throws of the industrial revolution, the industrial smog made having a grey color harder for predators to catch." (Rutledge, 2011) This created an influx of dark grey colored peppered moths in the urban cities in England. Speciation is the creation of a new species through the process of genetic mutation, or adaption. A direct isolation or change in environment can lead to speciation. Adaptations can occur from both abiotic and biotic factors. An adaptation is a genetic change to the structure or behavior of an organism to aid in its survival. (Scott-Elliot, 1904) However there are downsides of adapting to a highly unique environment. One of those downsides is that the organism with these traits cannot survive in any other environment due to the high level of specialization. The knowledge of where seeds are selected from is critical in the field of forestry. When seedlings from different elevations were taken and replanted in other gardens that differ in altitude the results were remarkable. The seedlings that were selected from high elevations struggled to grow in lower elevations, however they grew perfectly as the elevation increased. The converse proved true for seedlings selected from the lower elevations. This experiment was performed by Professor Adolf Engler. In a later experiments performed by many different scientists all over the world, one detail became apparent. The seedlings that were taken from very high elevations began growing in spring, and lost their leaves long before the seedlings grown at lower elevations. A specific example of this is that the *Picca Ecvelsa* was planted at 670 meters above sea level, when they were harvested at 1550 and 1800 meters, the plants began their growth one week before seedlings selected from an elevation of 546 meters. The plants from high elevations also stopped growing between 6 and 8 weeks before the others. (Scott-Elliot, 1904) This shows a very obvious behavioral adaptation. The adaptation is due to the fact that the growing period and growing conditions are different as elevation changes. This is evidence that climatic adaptations are acquired through inheritance. Other characteristics that seem to be inherited by the high elevational trees includes thinker bark and proportionally longer roots systems. Clear evidence of abiotic adaptation is present in this series of comparative experiments. Temperature is one of the most powerful attributes that drives adaptation.

The reasons behind temperature decrease with the increase of altitude was cause for great debate all the way until the eighteenth century. De Saussure, whose work in Mont Blanc was the first real attempt to approach the question scientifically, is the reason we have an accepted average rate of temperature decrease with height. That rate is 6˚C km^{-1} in the free atmosphere. (Barry, 1981) This is known as the Environmental Lapse Rate. This is an approximation, or an average Lapse Rate. There are multiple other factors that dictate the rate of heat exchange with elevational increases. Those factors include: time of the year, time of day, climatic zone, type of air mass. Topography also plays an important role in the determination of climate, and by extension air temperature. Large mountains and plateaus are able to drastically effect the wind patterns of a region and create areas of low and high pressure. These areas of low and high pressure are what drive the weather systems. The elevation of the mountain or plateau effects the severity of the heat exchange that is experienced by the air passing over the slope. An ecosystem that is set at a higher elevation will experience much difference climate changes throughout the seasons. Temperature generally decrease with an increase in elevation, this is supported by the work of Chris R. McGuire in his research regarding the change of temperature on the rocky mountain range over time The objective of this study was to mark the differences of temperature as compared to previous measurements. While achieving this result, other measurements were gathered that show the constant difference in temperature when dependence factor is elevation instead of time. The Max Temp, Min Temp, and Mean Temp was calculated over the 56 year period. Even though these calculations were not the main objective of this experiment, they are still valuable when attempting to show the difference in temperature in relation to elevation. The results show a definitive degrees in average temperature as you go from lower elevation to the higher elevations. The p values for all measurements taken were equal to or below 0.05. This shows empirical evidence that temperature in the Rocky Mountains decreases as elevation increases.

To understand radiation, the terms that are used must be understood first. The first term that is crucial to understand radiation in terms of elevation is transmittance. This is defined as the measure of lost energy as a result of scattering and absorption of light by molecules, airborne particulate matter, and aerosols in the atmosphere. Transmittance is defined by the path the radiation takes through the air, also the length of the path taken and by the specific properties of the atmosphere. Angle of the sun is also important because of the fact that angle determines the length a beam of radiation must travel and the thickness of the atmosphere it must travel through. In order to determine transmittance, the idea of optical air mass is applied. Optical air mass is defined as the amount of air a single beam of radiation encounters while traveling through the atmosphere and is also partially dependent on the atmospheric composition. (Landsberg, 2012)

Radiation is something that is often overlooked when considering the abiotic factors at play in a specific ecosystem. In a pure, dry atmosphere solar radiation is affected directly by molecular scattering and by the amount of absorption of atmospheric gases. However when working with a real atmosphere the following factors must be taken into consideration: absorption from water vapor and attenuation by aerosol scattering. When referring to a mountainous area aerosol content is lower than at sea level, and the amount of water vapor in the atmosphere is usually below 700mb. (Barry, 2008) Due to these generally low levels at high elevations, there effects are diminished, causing higher levels of radiation to pierce through the atmosphere. The fact that water vapor is so concentrated in the lower troposphere means that the increase in solar radiation is almost exponential from sea level to around 2000 meters. The level of direct beam radiation on a clear sky is also directly impacted by elevation due to elevations direct relationship with air pressure and turbidity. For a cloudless sky, global radiation is 32% higher at 3000 meters as compared to 200 meters. (Barry, 2008) This means an increase of 7-10 percent per km^{-1}. In conditions with overcast the increase was recorded at 9-11 percent per km^{-1}.

(Barry, 2008) This ratio increases with altitude however meaning that the cloud cover has little influence of the levels of radiation. The elevation of a mountain will also effect the levels of radiation absorbed due to the fact that at a higher altitude, the angle the beam of radiation changes, causing the beam to travel through a different amount of atmosphere.

The level of precipitation is often the strongest determining factor in determining Ecological Zone Classification. The topography of an ecosystem shapes the weather patterns of that ecosystem, and in some cases other ecosystems. This can be found in the North-Eastern corner of the United States where the Cascade Mountain Range creates regions of think vegetation on the eastern coast, but on the west side of the mountain a must dryer biome is found. The Cascade Mountains have effected multiple ecosystems.   Mountain ranges act as barriers for moisture, trapping the moist air on one side forcing the precipitation to occur in an extremely uneven manner across the area. This effect can be seen on a global scale as well. Since mountains occupy 20.2% of the Earth's surface, global weather patterns are effected. (Mielke, 1989) Mountains ability to trap moisture and force heavy precipitation patterns in some places and arid conditions in other, makes them appealing when trying to understand the relationship between plant growth and precipitation. Precipitation in subtropical precipitation patterns follow a steady increase up until an elevation of about 3500- 4000 meters, after that it steady decreases. (Nagy, 2009) However in the lower latitudes, the trends become more dependent upon the position of the mountain in relation to the circulatory pattern it is located within. Precipitation patterns changes drastically when compared to the low latitude tropical region to the subtropical regions.

Using the Sierra Nevada mountain range as an example, a clear trend can be found with precipitation and elevation. The peak named de Santa Marta in Columbia, the slope was described as steep and direct from sea level to about 6000 meters. Using the least square method, the height of maximum rainfall is easy to calculate to be 1660 meters above sea level. However above this level was found to be an ombriphilous forest located above lower level of the cloud line. This suggest that the real effective hydrological maximum is not 1660 meters, but rather a much higher 2300 meters. (Reimer, 1970) This shows that with an increase in elevation the precipitation increase as well, up until a certain point

Several attributes of soil have been shown to be directly affected by an increase in elevation. Some of the factors that are directly influenced by an increase in altitude is the depth of both B and O/A Horizons. (Bromley, 1995) The increase of elevation is also associated with a drastic decrease in soil temperature. The composition of soil also changes mildly with an increase in elevation. The percent sand recorded showed a decrease of approximately 1% per 152.47 feet gained in altitude between the elevations of 6400 feet and 9600 feet. (Bromley, 1995)

Conversely the percent silt was shown to increase with elevation, at a rate of approximately of 1% per every 188.23 feet between the same ranges. In addition to the composition being altered, the nutrient availability was also shown to change with elevation for both Magnesium and Potassium. The increase of about 1 mg/kg per 63.82 feet and 1 mg/kg per 30.92 feet respectively. (Bromley, 1995) This shows just how influential the factor of elevation can be in terms of soil composition, nutrient availability, temperature, and depth of both B and A/O horizons.

The plant life of an area is immeasurably affected by the abiotic environment in which they reside in. elevation and temperature play critical roles in the success of plant species. When placing two different type of tree species at different two different altitudes the results will reflect the impact those factors have on the plant. The results are based upon a multiple of different attributes the plant exhibits. Those factors include: plant height, width, biomass, seed yields and oil content. When the two species were planted at both 300 meters and 1200 meters the results followed a negative trend with the increase in altitude. (Dierig, 2006) Plants that were being grown at the lower elevations experienced as much as twice the height and width and up to 5 times the biomass. The seed yields had similar results. The oil was the only factor not affected by the change in elevation. This study shows the impact elevation has on plant success. Showing that not all plants will be able to acclimate to high elevation ecosystems. It is important to understand that the effects of elevation directly influence the physiology of a plant. The rate of plant growth is mainly dictated by the amount of Carbon Dioxide that is absorbed through its leaves. With an increase in altitude also comes a decrease in air pressure, meaning that less air is available for plants to absorb leading to the stunted growth of plants at higher altitudes. The way plants absorb carbon dioxide from the air is through the part of the plant known as the stomata. The stomata's functionality is dependent upon the amount of water and carbon dioxide in the air. With restricted water availability from the lack of air at high elevations the stomata is not able to open as wide. When this is coupled with the lack of CO^2

this causes the rate of photosynthesis to suffer. (Gale, 1972) As a result of a slow rate of photosynthesis, the plant is not able to produce as much energy for growth when compared to the same plants at lower elevation.

Elevational gradients that relate to species diversity are as numinous as any other type of gradient. With that said there are patterns in the data. While the mechanisms that drives every elevational species diversity are still heavy debated, the notion that species diversity peaks in the mid elevations is more widely accepted. (Sanders, 2011) Across the world in multiple different locations boasting drastically different climates, the diversity patterns differ slightly but what was astonishing was that the underlying causes were remarkably similar within each gradient.

A forests ability to be successful hinges on the ability of that forest to promote primary producers. The foundation of all major food chains are based in primary producers. Plants act as a great example for primary producers and are often a central component in any forests energy cycle. Trees have been shown to lose growth potential from a variety of factors including size, competition, and altitude. Diameter growth rate was shown to decline with altitude, this is attributed to a shortened growing season and a lower average growing season temperature. (Coomes, 2007)

Ecological Zone Classification is a scientifically rigorous manner of organizing areas of land into groups based on several factors. Those factors include: average temperature, precipitation, geographic range, elevational range, vegetation type. This method of identification proves useful when trying to describe a habitat or study area. (Rome, 2001) With these parameters, five individual main categories exist. These general classifications are known as “Domains”. Each domain generally has several subcategories listed under it. The first domain is Tropical. With an average temperature of 18 degrees Celsius, and are generally located between the tropic of Cancer and the tropic of Capricorn. With the lowland zones existing between 1000-and 1500 meters. The subcategories of tropical are determined generally by level of precipitation and topography. The first subdomain of tropical is the tropical rainforest, which annual precipitation is at least 1500 mm – (often above) 2000 mm. The next subdomain is tropical moist deciduous forest, this is classified by a precipitation level between 1000 mm and 2000 mm and has a summer rain and a between a 3 and 5 month dry season. The dry tropical forest is defined by a 5 to 8 month dry period and an annual precipitation range of 500 mm and 1500 mm. A tropical shrub-land is characterized by having an area that evaporation levels are greater than the precipitation level, with the precipitation level existing between 200 mm and 500 mm. The tropical desert is an area defined by the previous general criteria but has no rain season. The last type of subdomain is the tropical mountain system, this is defined by the topography of the area more so than the climate, it is mainly defined by the varying altitude of the area. The next major domain that exists is known as Subtropical. Subtropical forests have a period of at least 8 months above 10 degrees Celsius, is located between the latitudes of plus and minus 25 to 40 degrees. The first subdomain is labeled subtropical humid forest, this is defined by an evenly distributed raining season with a high level of humidity. The next subdomain is called subtropical dry forest, a dry forest has Mediterranean climate but with dry summers and humid average winters, with a rainfall level falling between 400 mm and 900 mm. A subtropical steppe is defined by having a higher level of evaporation than precipitation. The last type of subdomain is a subtropical mountain system, which is again classified by the varying altitudes. The third major domain is what is known as Temperate, this is classified by geographically being located in the middle latitudes and an average temperature of around 10 degrees Celsius. The first subcategory for this major domain is what is known as a temperate oceanic forest, this forest is defined by its mild climate throughout the year but approaches freezing during the winter; however it never dips below 0. This zone is also humid with average amounts of rainfall depending on your elevation. The next subdivision is temperate continental forests. They are classified by their tendency to reach below freezing temperatures in the winter and having colder snowier winter seasons. They also exhibit rainfall decreases from seaward margins and less so towards the center. Temperate steppes are characterized by an area having a higher level of evaporation than precipitation, but also experiencing periods of extreme cold. Temperate deserts have an all year dry season but also are prone to periods of server cold. The last is known as a temperate Mountain systems, these have very boreal characteristics, with snow cover most of the year. The fourth type of domain is known as Boreal. This is subarctic area, usually located between 50-70 degrees above and below the equator. It must have at least one month of above 10 degree Celsius weather. Another characteristics is a wide range of precipitation and temperature. The first subdomain is known as boreal coniferous forests which have at the most 3 months above 10 degrees Celsius. But have long harsh winters, with unusually warm summers. A boreal tundra woodland is similar but is colder and experiences much harsher winters. The last type of subdomain is known as boreal mountain system, which is defined by the open woodland and shrubs combined with the brutal cold and continuous permafrost. The last domain has not subdomains and is called Polar. A Polar domain has complete permafrost, and all months are below 10 degrees Celsius, they exist between the latitudes of 70 and 90 on both hemispheres and offer little habitat for life. Knowing how to classify a region is imperative to being able to understand the abiotic and biotic factors at work there. Nicaragua processes one of the largest untouched lowland tropical forests north of the Equator, with an area of roughly 7.9 million acres. (Rainforest Alliance, 2012) Nicaragua is losing forest at a rate of 1.3 percent per year caused by the increase economic demand for timber and from general human development. (Rainforest Alliance, 2012) Volcanoes in general get negative attention for their immense destructive capabilities. The potential for volcanoes to inflict damage on human life and on the environment is incomparable in nature. However, one of the little known long term effects is that volcanic eruptions can provide some the most nutrient rich soils on Earth, which can be attributed to the agricultural success of countries all over the world. (Fisher, 1997) An example of this success can be found in the Northern hills of Italy in the city of Naples. Naples is home to Mount Vesuvius, which erupted twice in recent history, once 12,000 years ago, the other 35,000 years ago. These eruptions ejected massive amount of material into the air and after it settled formed what is now known as tephra. The tephra has since eroded away producing extremely rich soils. New Zealand also owes most of its agricultural success to the volcanic loam the country is known for. Vegetation zonation is the pattern that often occurs in biomes that include mountains. It is easily identifiable due to the fact that many of the zones have very different tree populations. These canopies are very easy to differentiate between. The parameters of these ecotones has been shown to be defined by climatic factors that are associate with the Trade Wind Inversion. The process involved in mapping out the elevational zones are attributed to climate and vegetation physiognomy. Most classifications accept that there is a change from lowland forest to lower montane forest. Generally tropical mountains experience that change at an elevation of 1200 to 1500 meters. (Martin, 2010) The next clear zonation occurs between the lower montane and upper montane forest; which generally occurs at an elevation of 2000 to 3000 meters. The upper montane area is usually located at the "cloud level". The limit of the upper montane forest is generally represented by the frost line which discourages the growth of most tropical flora. The vegetation in this area is very distinguishable from the lower montane forest. The canopy height is noted as low, and the tree population is often described as twisted and mangled. The plants leaves are generally smaller in relation to the stem. The causes of these physical attributes can be linked to changes in soil fertility, high wind tendencies, higher levels of UV radiation, and higher humidity. The area above this cloud forest is often known for its "tree line". The tree line marks the upper limit of vegetation, the point where plants are no longer able to grow. This tree line is determined by the geographic setting of the mountain, but can often be found between an elevation of 3600 and 4000 meters. (Martin, 2010) These general elevations are subject to influence when small isolated mountains are being studied. This effect is known as the 'Massenerhebung' effect. This effect is caused by the fact that larger mountains contain more mass and the more mass an object has the more solar radiation it is able to absorb; this changes local climate patterns and as a result, local vegetation patterns. These elevational based factors very obviously have an influence on the plant life hosted in that biome.

Hypothesis

Null 1: There will be no significant change in DBH with a change in elevation on the Maderas Volcano.

Alternate 1: There will be a significant increase in tree DBH with an increase in elevation on the Maderas Volcano.

Null 2: There will be no significant change in forest density with a change in elevation on Maderas Volcano.

Alternate 2: There will be a significant decrease in forest density with an increase in elevation on Maderas Volcano.

Study Area

Nicaragua is located in Central America south of Honduras and north of Costa Rica between the latitudes of 15N and 10N. Nicaragua's climate is broken into three subcategories. The first category is the Pacific Lowlands; it is located on the west side of the country. The second is known as the North Central Highlands located in the northern central portion of the country. The last geographic region is known as the Atlantic Lowlands. Conception is located in the western portion of the country which means the region is falls under is the Pacific Lowlands. The Pacific Lowlands generally consist of broad, hot fertile plans. However, in the southern portion of the country Ometepe Island is located in Lake Nicaragua. It was formed from the two volcanos located in the lake. Ometepe Island consists of two volcanos, the largest is named Maderas which has a peak of 1,394 meters. Maderas is a dormant volcano. Maderas is visibly more vegetated when compared to Conception. The second volcano is named Maderas, it rises to a maximum elevation of 1610 meters. Maderas is known for it rich cloud forest and unique crater lagoon. I will be gathering my data on the east facing slope of Maderas. Taking measurements at three individual elevations.

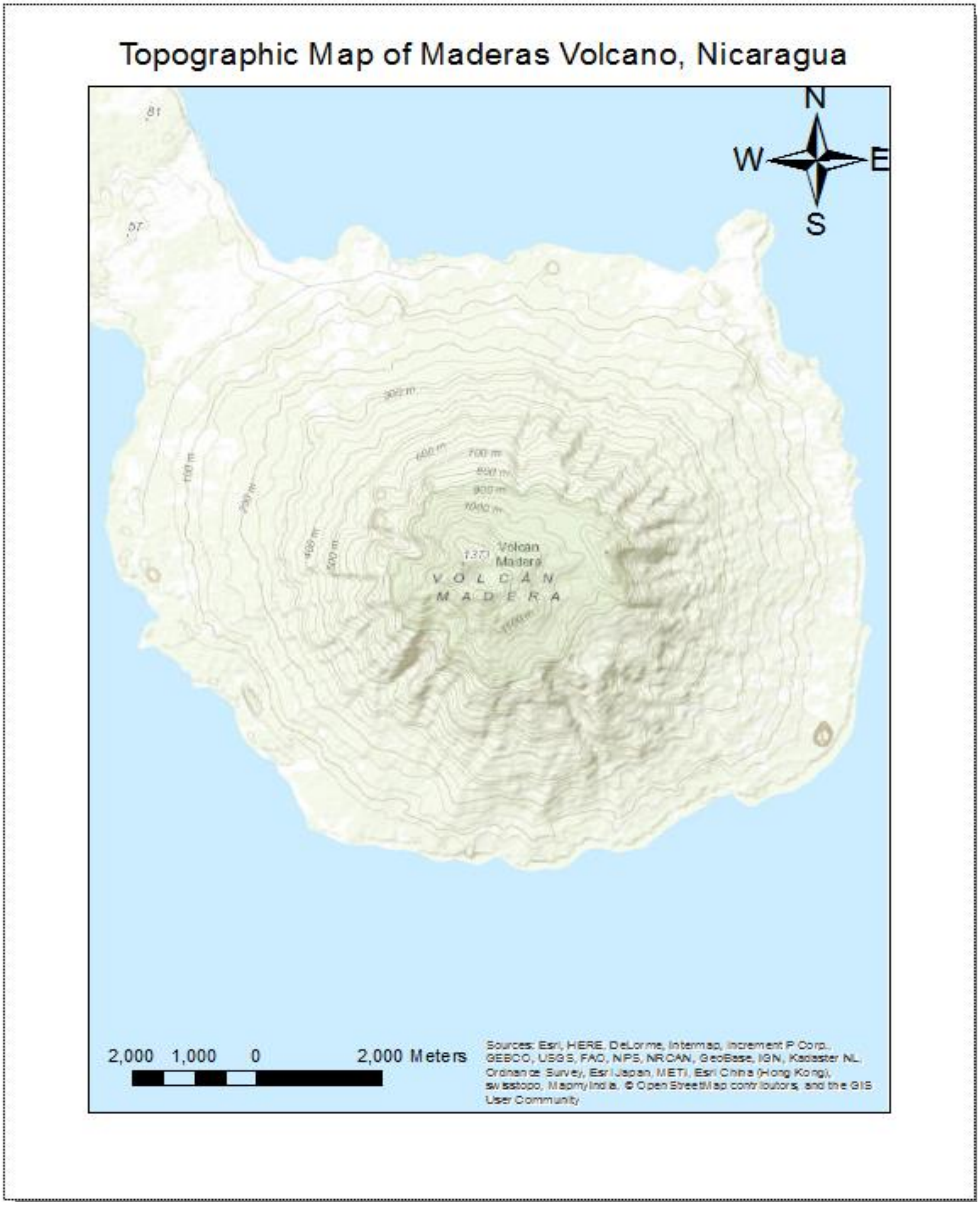

Figure 1 – Topographic map of Maderas Volcano, Nicaragua (Arc Map 10.4)

Field Methods

Data Collection Methods

Point Center Quarter method was used to gather data including forest density and DBH (Cotton & Curtis 1956; See figure 2.1). An elevation of 300 meters above sea level was reached before measurements could be taken. A marker flag was placed down to mark the beginning of the transect line. A physical tape measure will not be used due to the extremely high density of the study area, for the transect line, instead the 100 meters was paced out. Starting at 0 meters a marking flag is placed. This step is repeated every 10 meters. This created 10 individual sample points. At each of these sampling points an imaginary coordinate plane was placed, with the marking flag representing the origin. The positive y axis is always pointing towards the summit of the mountain. This quadrant plane divided the sample area into 4 quadrants. In each of the quadrants, the tree that is the closest to the marker flag, the origin, was recorded. The distance to the flag was recorded along with the diameter at breast height. This is known as DBH. DBH will only be measured for tree with a DBH of greater than 5 cm. After all 4 quadrants were sampled 10 uniform, one meter long paces were taken in the direction of the summit and the process is repeated. This is process was repeated a total of 10 times per elevation being studied. The following elevations are the location of the transects: 308 meters, 646 meters, and 914 meters. This will result in a total of 3 transect lines. With 10 density measurements, and 120 DBH measurements. This whole transect process is repeated at two other locations up the slope of the mountain to give a complete profile of the mountainside.

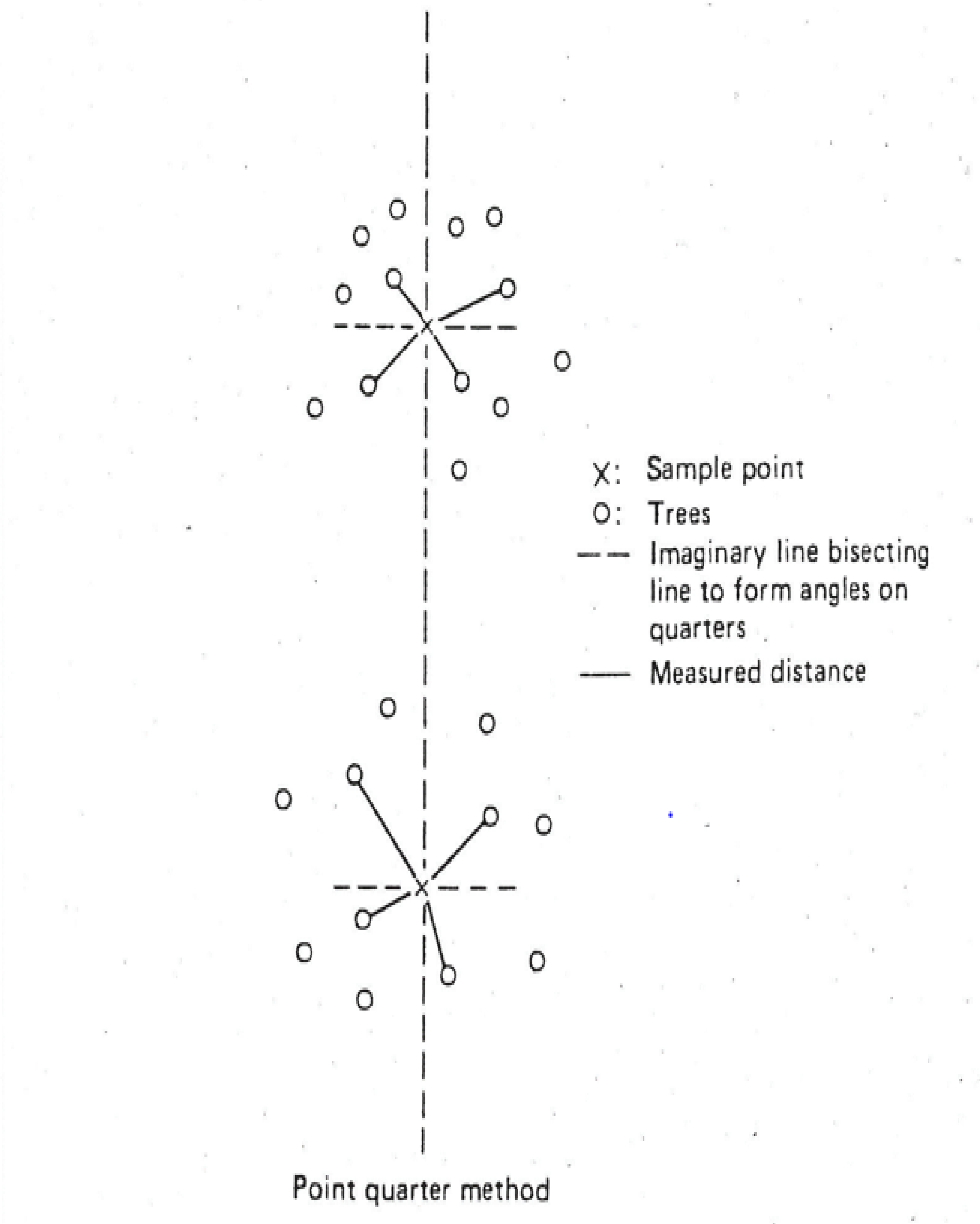

Figure 2 - The Point Quarter Method of sampling forest stand

Data Analysis Methods:

The traditional Point Center Quarter method requires that each tree that is sampled has its species recorded. In this study the species was not recorded. Instead of breaking down the data by species, this study will breakdown the data by DBH. Each size class is having a range of 10 cm. Each transect has 5 size classes. Class sizes are listed alphabetically, “A” representing the smallest class, and “E” representing the largest class. These two charts show the same data, but the bins in which data is placed is labeled differently. The data was analyzed by grouping by size class at each elevation, because with just 3 transects the data would not have worked well being treated as continuous. With the data placed into “bins” the question of a difference between elevations could be more conclusively answered.

Results

Overall Analysis

When looking at the mountain as a whole; 120 DBH measurements were taken, 40 at each of the three testing sites. The low elevation site had a sample mean of 22.93 cm. With a Margin of Error of 3.07 and a 95% confidence interval of 19.86 and 26.00. The mid elevation sample mean of 23.28 cm. With a Margin of Error of 3.20 and 95% Confidence Interval of 20.08 – 26.48. The high elevation site had a sample mean of 27.8 cm. The Margin of Error of 3.64 and a 95% Confidence Interval of 24.16 – 31.44. The P value for the DBH measurements was calculated to be roughly 0.1043 (See Table 1). The P value for the distance to center measurements were calculated to be much lower at about 0.0110 (See Table 2). The total density at the low elevation was measured to be the highest, with the mid elevation being the second largest, and the high elevation having the lowest total density (See Fig. 5).

Table 1- Single Factor Anova of DBH measurements at each elevation

Anova: Single Factor for DBH						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Low	40	917.4	22.935	98.47464		
Mid	40	931.4	23.285	106.9998		
High	40	1101.9	27.5475	137.88		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	527.5542	2	263.7771	2.304707	0.104302	3.073763
Within Groups	13390.82	117	114.4515			
Total	13918.38	119				

Table 2: Single Factor Anova of Distance from Center measurements at each elevation

Anova: Single Factor						
Sites	*Count*	*Sum*	*Average*	*Variance*		
Low	40	40.65	1.01625	0.174234		
Mid	40	42.18	1.0545	0.119856		
High	40	50.02	1.2505	0.110333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.263362	2	0.631681	4.685787	0.011025	3.073763
Within Groups	15.77252	117	0.134808			
Total	17.03588	119				

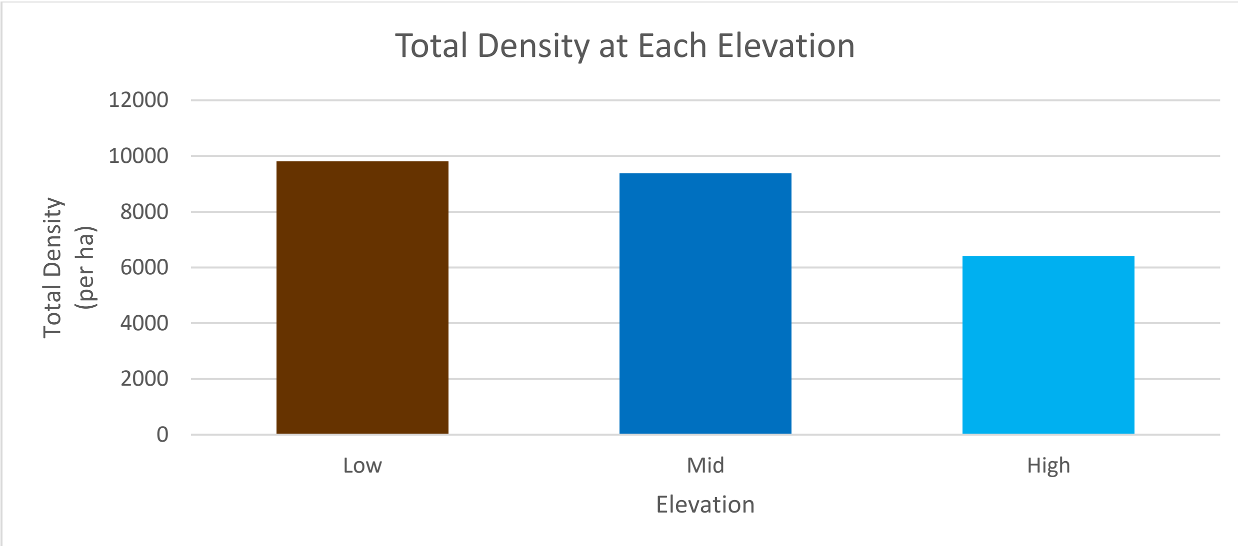

Figure 3- Comparative graph of total density of tree at each elevation.

<u>Analysis by Elevational Sites</u>

Low Elevation Site:

At the first test site 40 DBH measurements were recorded along with the same number of distance to center measurements. The first of the values that was calculated was relative density; at low elevations the size class “a” and “b” account for 80% of the total density at the lowest elevations. However relative dominance at low elevations favors size classes “b” and “c”; with these two size classes making up the majority of data shown, meaning the even though there are more trees in the “a” and “b” classes, “b” and “c” class trees dominate more at low elevations. Relative frequency shows the same trend that was shown in the relative density graph; the smaller trees are favored in terms of relative frequency at low elevations. (See Fig. 4) This trend of smaller trees being favored can be seen with the Relative Importance Value; at low elevations trees in the “a” and “b” classes occupy are on average 120 points above the larger trees in size class "d" and "e" (See Fig. 5). The average DBH at low elevations is 22.9 cm; the distribution of this data has a skewness of 1.03 meaning it is very right tailed (See Table 3)

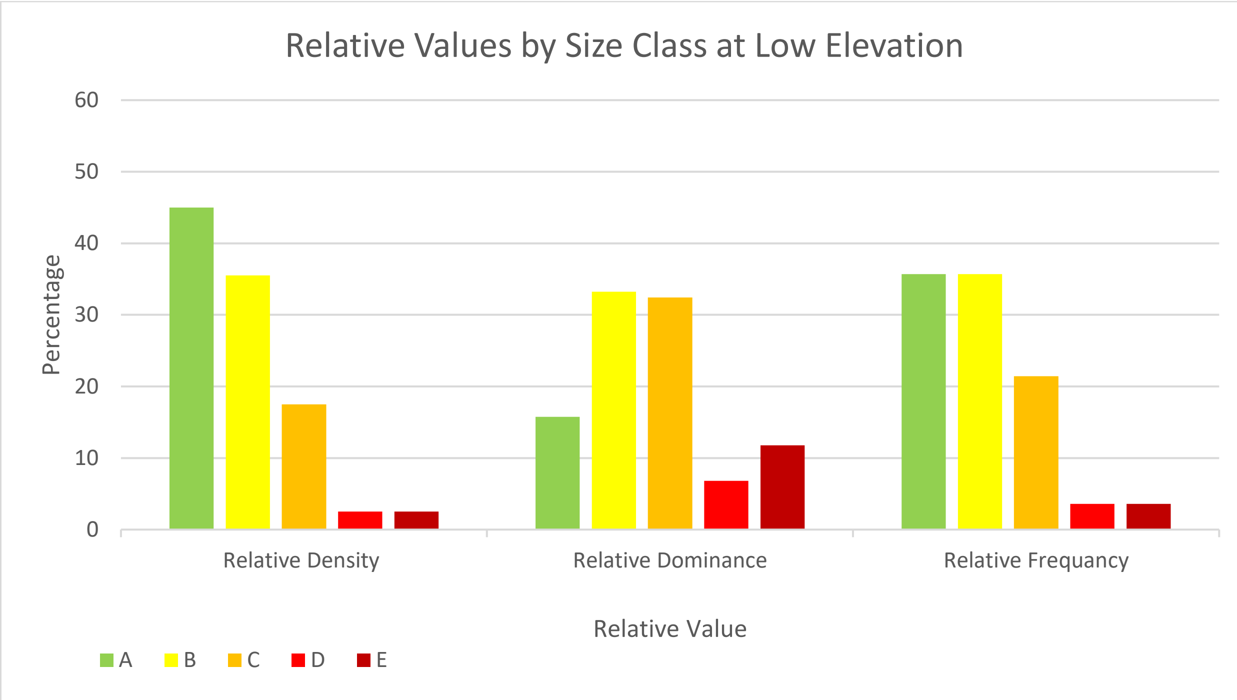

Figure 4– Histogram of Relative Density, Relative Dominance, and Relative Frequency by size class at the low elevation testing site

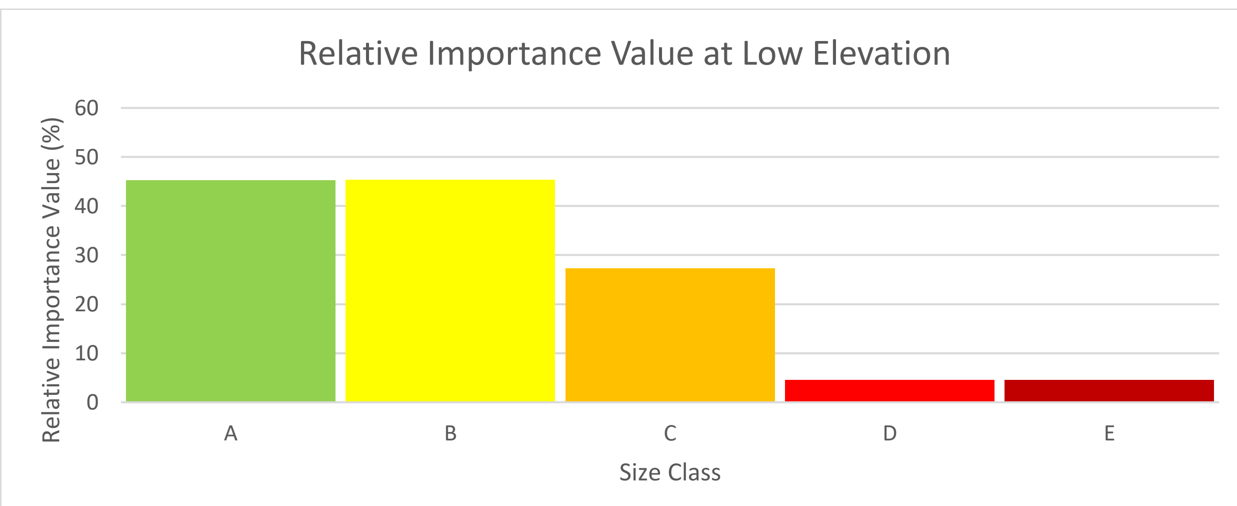

Figure 5– Histogram of Relative Importance Value by size class at the low elevation testing site

Table 3 – Table of descriptive statistics for the DBH data collected at the low elevation site.

Low Elevation Descriptive Statistics	
Mean	22.935
Standard Error	1.569033
Median	21.15
Mode	#N/A
Standard Deviation	9.923439
Sample Variance	98.47464
Kurtosis	1.318355
Skewness	1.033849
Range	45.5
Minimum	9.4
Maximum	54.9
Sum	917.4
Count	40
Confidence Level (95.0%)	3.17367

Mid Elevation Site

Just as at the low elevation site, 40 DBH and 40 distance to center measurements were taken at the mid elevation site. The Relative Density at the mid elevation site is completely dominated by the “a” size class representing 45% of the site, while class “b” and “c” occupy the majority of the remaining data. The largest size classes, “d” and “e”, represent less than 5% of the total relative density. Relative Dominance has more of a bell curve shape, with the size class “c” having the largest percentage. This meaning that even though there are more small trees at mid elevations, the medium sized trees tend to dominate. The Relative Frequency shows a similar trend as was shown with Relative Density, the smaller trees making up the majority of the data while the larger trees represent almost none of the data points taken. (See Fig. 6)

Smaller trees are more important than the larger trees at the mid elevation, this is shown because the size class "a" has the highest Relative Importance Value and each class has a low RIV than the one before it, except the with size class "e", because size class "d" had zero. (See Fig. 7) The average DBH of trees at the mid elevation site is 23.2 cm; with the distribution of this data having a skewness of 1.01 meaning it is a heavily right tailed distribution. (See Table 4)

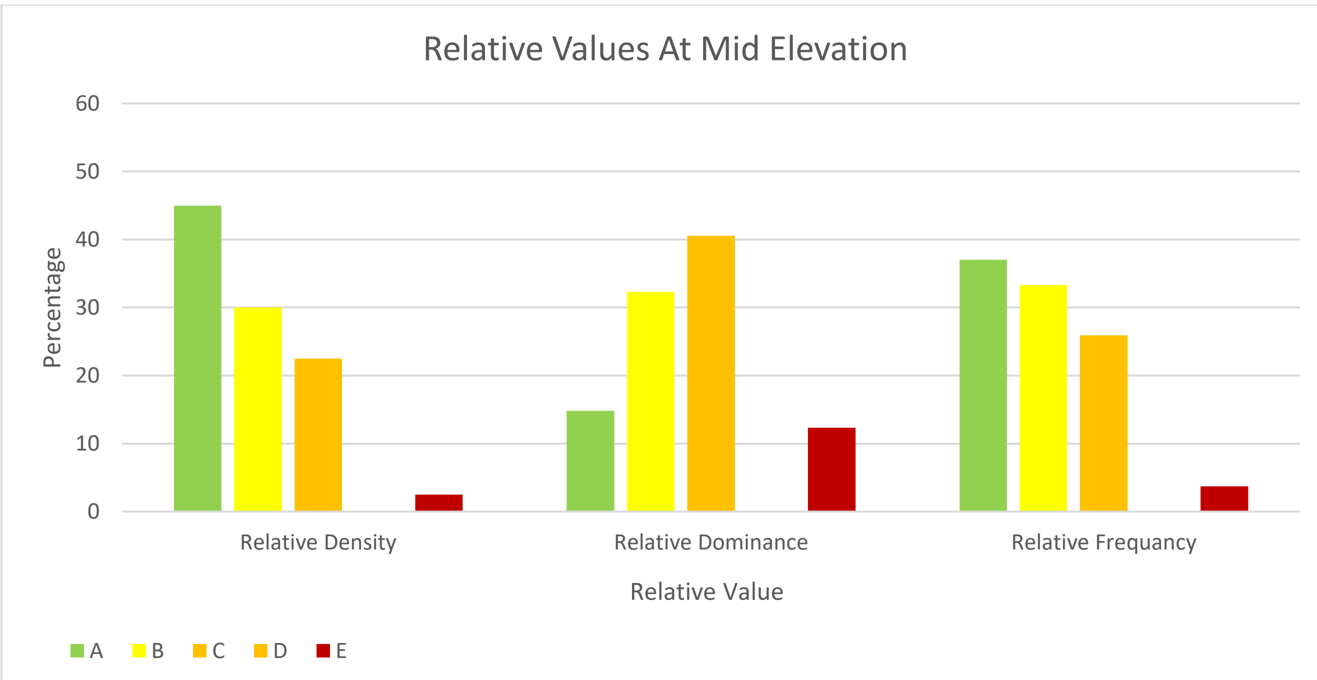

Figure 6– Histogram of Relative Density, Relative Dominance, and Relative Frequency by size class at the mid elevation testing site

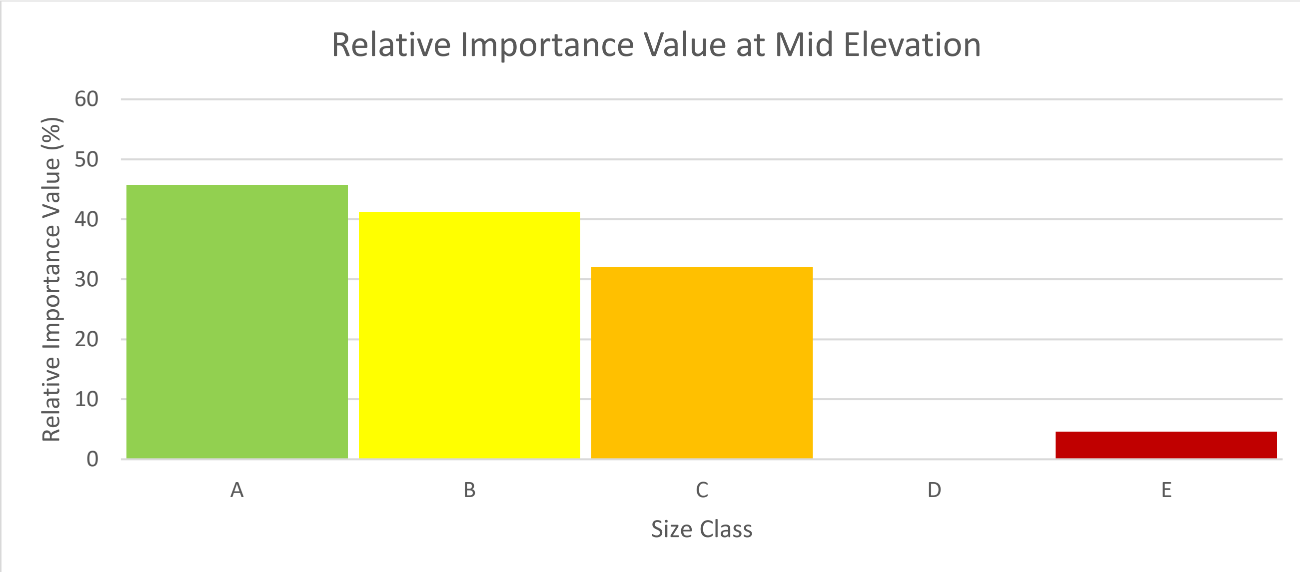

Figure 7- Histogram of Relative Importance Value by size class at the mid elevation testing site

Table 4 – Table showing the descriptive statistics for the data collected at the mid elevation site

Mid Elevation Descriptive Statistics	
Mean	23.285
Standard Error	1.635541
Median	21.35
Mode	9.8
Standard Deviation	10.34407
Sample Variance	106.9998
Kurtosis	1.595238
Skewness	1.013902
Range	48.3
Minimum	9.6
Maximum	57.9
Sum	931.4
Count	40
Confidence Level (95.0%)	3.308194

High Elevation Site

From the 40 DBH and distance to center measurements that were collected at the high elevation site, the following calculations were performed. The first calculation preformed was

Relative Density and at the high elevation site, the smallest size class, “a”, only represented 20% of the Relative Density, the next two size classes represent the majority, with a combined Relative Density of about 62%. The two largest size classes, “d” and “e”, are responsible for 12.5% and 5% respectively. Relative Dominance has the majority of its data located in the size class “c”. a common bell curve can be seen in this data set, with a slight negative skewness. Meaning that more data exists in the two largest size classes, “d” and “e”, when compared to the two smallest size classes, “a” and “b”. Relative Frequency has a similar pattern to the Relative Density. The “a” and “b” size classes represent the majority of the data; with the “b” size class having the highest frequency reported at about 32%. When increasing class size after class size “b”, Relative Frequency drops (See Fig. 8). The Relative Importance Value places the highest value on the “b” class size, with a similar data pattern to the Relative Frequency value (See Fig. 9). The mean for the DBH data collected at the high elevation site was recorded at 27.5 and the DBH data frequency distribution has a skewness of 0.45 (See Table 5).

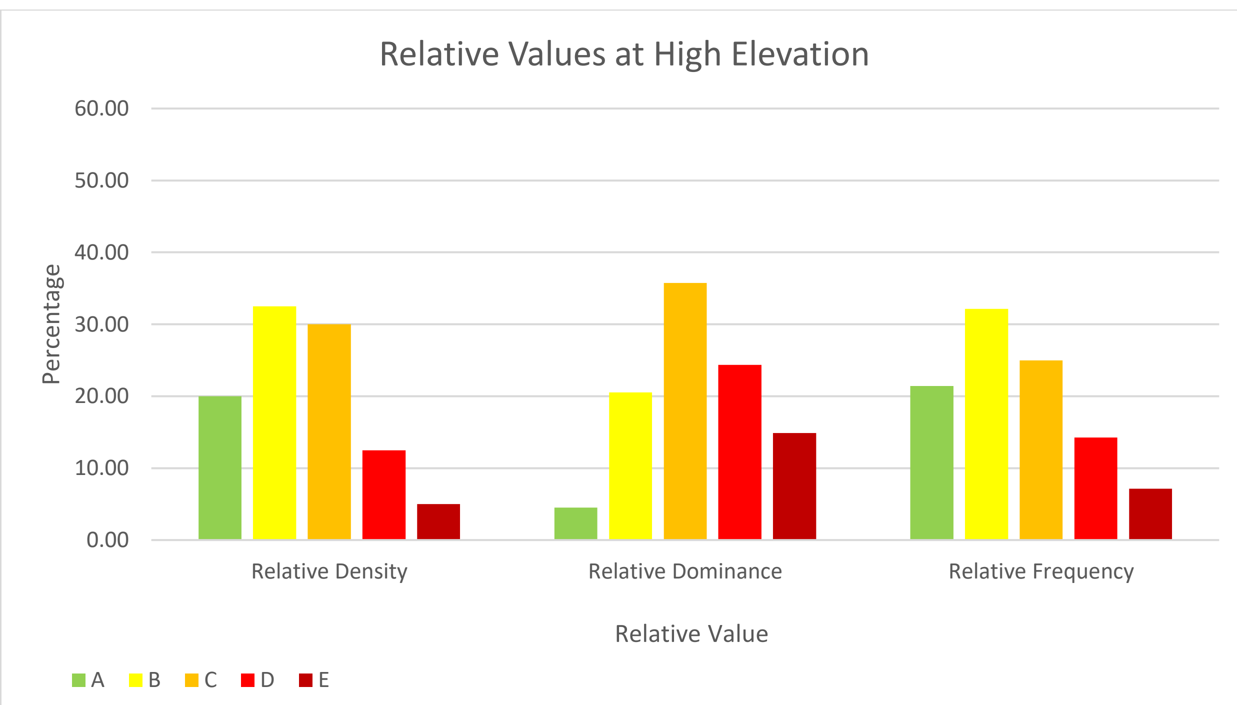

Figure 8- Histogram of Relative Density, Relative Dominance, and Relative Frequency by size class at the high elevation testing site

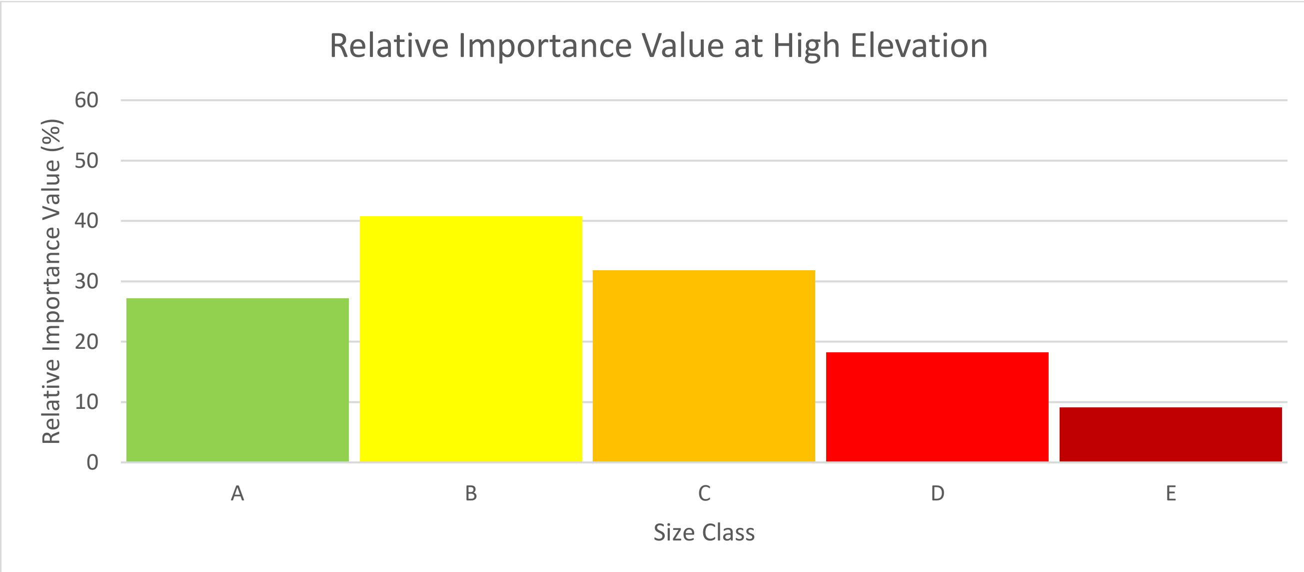

Figure 9- Histogram of Relative Importance Value by size class at the high elevation testing site

Table 5 – Table showing the descriptive statistics for the data collected at the high elevation site

High Elevation Descriptive Statistics	
Mean	27.5475
Standard Error	1.85661
Median	27.8
Mode	10.8
Standard Deviation	11.74223
Sample Variance	137.88
Kurtosis	-0.23803
Skewness	0.454179
Range	48.5
Minimum	9.8
Maximum	58.3
Sum	1101.9
Count	40
Confidence Level (95.0%)	3.755348

Collective Comparison

When comparing relative density of the trees at each elevation by class size a pattern becomes clear. The smallest trees in size class “a”, have a much higher relative density in the low and mid elevations rather than at the high elevations. However, “c” class trees show a different trend. At the low elevation they represent a lower Relative Density than the mid elevation, and the mid elevation a lower Relative Density than at the high elevation. The largest trees, found in size class “e”, continues this trend; at low and mid elevations the larger trees represent half the Relative Density than size class “e” trees do at high elevations (See Fig. 10).

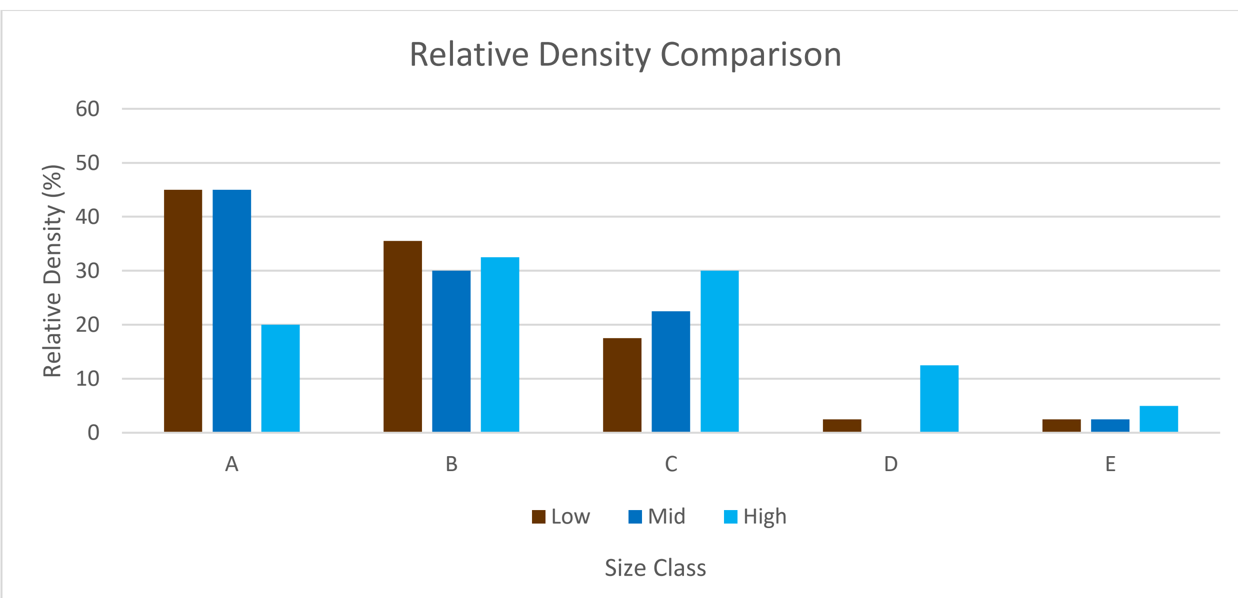

Figure 10– Comparative bar graph of Relative Density at each elevation and size class

The Relative Dominance of “a” class trees show that they have the highest dominance at the low elevations, the second highest at mid elevations and the smallest dominance at high elevations. This trend continues with “b” class trees, however with larger values. The trend changes when comparing size “c” trees, with the largest Relative Dominance value coming from at the mid elevation, the second largest value can be found at the high elevation and the smallest value is located at the low elevation. The values for “c” class trees overall have the largest values of any tree size class. The “d” size class trees show the highest dominance at the high elevation, no dominance at mid elevations and a minimum Relative Dominance at low elevations. A similar trend is found with “e” size class trees, the highest Relative Dominance in the high elevations, and much lower Relative Dominance at the low and mid elevation (See Fig. 11).

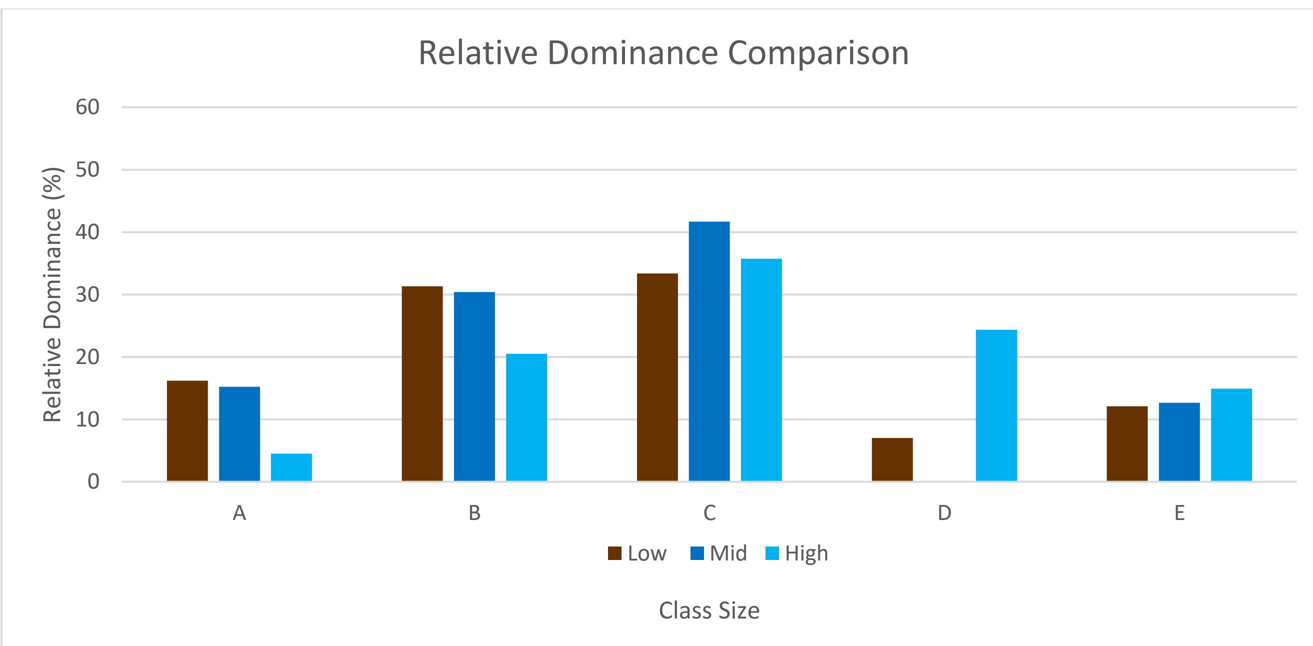

Figure 11- Comparative bar graph of Relative Dominance at each elevation and size class

The Relative Frequency of the small “a” class size trees are the highest at the mid elevations, followed closely by low elevations. The high elevation site reported almost half of the Relative Frequency of the mid elevation. The “b” class trees are most frequent at the low elevations, followed by mid elevations and high elevation respectively. The “c” size class trees show the highest frequency at mid elevations, the second highest frequency at high elevation and the lowest frequency at low elevations. The largest disparity is found in the “d” class trees, with the largest frequency coming at high elevations and the second highest value is at low elevations with about 1/3 the relative of the high elevation; also having no data for the mid elevation site. The largest trees, found in size class “e”, has the highest frequency at high elevation followed by mid and low elevations sharing the same low value of <5%. (See Fig. 12)

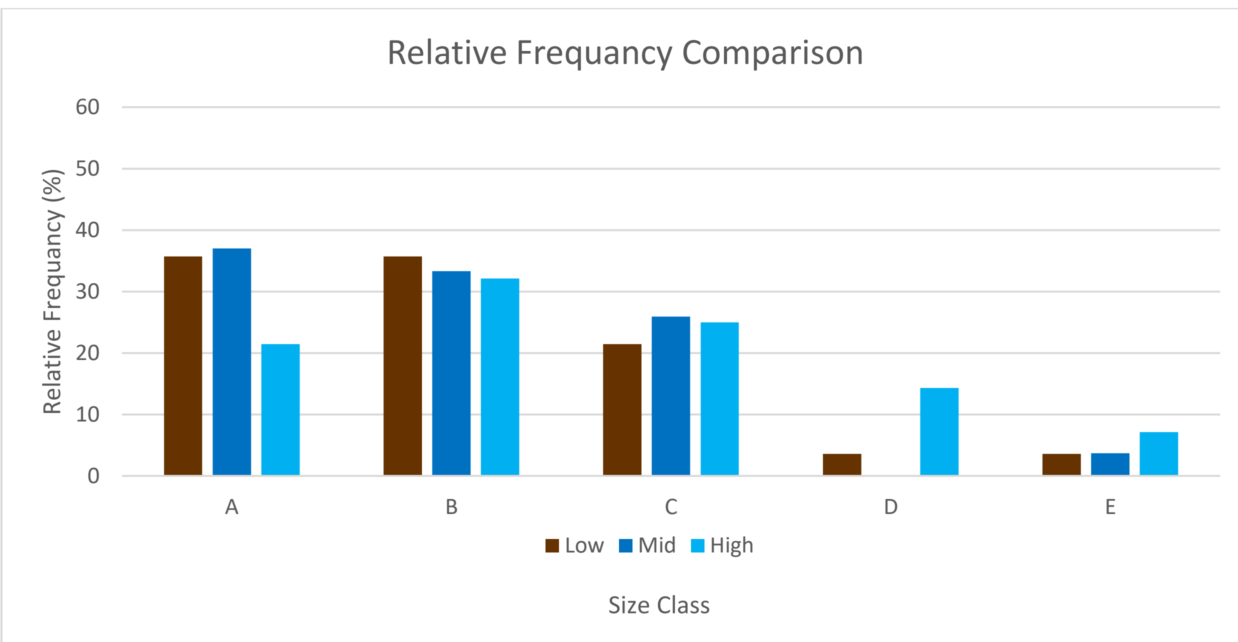

Figure 12– Comparative bar graph of Relative Frequency at each elevation and size class

The Relative Importance Value reports that with size class “a” trees they are the most important in the low and mid elevations and less important at the high elevation. The next largest size class, size class “b”, reports that at low elevations these trees are the most important, and are equally important at mid and high elevations. With size class “c” trees the elevations where they are most important is at the mid elevation, followed by the high elevations and lastly by the low elevation. The “d” class trees show the highest importance at high elevations, the second most importance at low elevation and no importance at mid elevation. Lastly the largest class size “e” shows the highest importance of large trees being at the highest elevation and the lowest importance at the low and mid elevation sites. This shows an opposite trend to the smallest “a” class size trees. Meaning that at low elevations smaller trees are more important, while at higher elevations larger trees are more important (See Fig. 13).

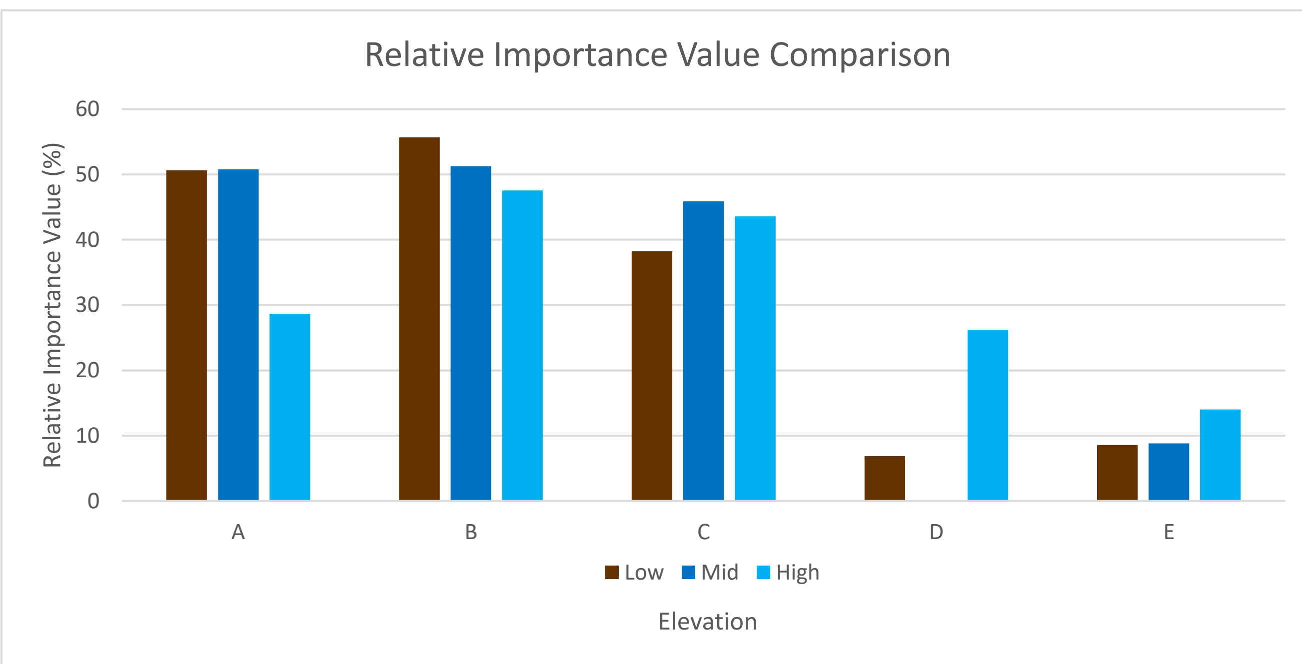

Figure 13- Comparative bar graph of Relative Importance Value at each elevation and size class

Discussion

Even though the mean DBH of trees collected at the low elevation site was calculated to be 22.9 cm, which is roughly 5 cm less than that of the high elevation site, the DBH means when compared to each other reported a p value of 0.10 which is double the accepted value for P; thus meaning that the DBH data collected is not statistically significant but it is close enough that further investigation is recommended. The null hypothesis that there will not be a significant change in DBH with a change in elevation of Maderas, Volcano cannot be rejected.

The Distance to Center data collected also had a great disparity between the low elevation mean and the high elevation mean. However, the Distance to Center values were statistically significant, receiving a p value of 0.01 which is lower than the accepted 0.05 threshold. This means that the decrease in density is statistically significant. A clear change can also be seen in the Relative Importance Value of small trees are much more important at low elevations, while larger trees become more important at the higher elevations. We can reject the second null hypothesis, that there will be no significant change in forest density, with a change in elevation on Maderas, Volcano; and suggest the alternative hypothesis that there is a significant decrease in forest density with an increase in elevation on Maderas, Volcano.

The most significant and telling information about the changes that occur with elevation come from the Relative Importance Value. Relative Importance Value is used to tell what species, or in this case class size, hold the most value to that specific ecosystem. RIV is a calculation that considers the Relative Density, Relative Dominance and Relative Frequency of size class at each location. At the lower elevation, the smaller trees are much more important what than the larger trees; however, at the high elevations the larger trees are much more important than the smaller trees.

The abiotic and biotic factors change drastically when travelling from low to high elevations on the mountain such as; soil type, soil moisture, and precipitation. These changes are what are believed to be the causes behind the differences in density and tree size.

Some issues encountered while preforming this research included a strict time constant. This data was collected on a group hiking trip, meaning the three stops I had to make had to work around the groups schedule. A preferred system would have been to make multiple trips up the mountain to each elevation site, this would ensure better measurements. When a heavy time constant isn't in place, more accurate measurements can be taken, along with possibly more measurements per elevational site. More measurements would grant a much more accurate representation of what trends are occurring on the slopes of Maderas Volcano.

Conclusion

The change in forest density is a direct result of the abiotic and biotic factors at work on the mountain. An increase in elevation changes the environment drastically; precipitation patterns, soil composition, and radiation levels all change when elevation increases. The peaks of Maderas are characterized by the "cloud forest" that exists. This cloud forest contributes to the increase in precipitation that leads to an increase in growth of all types of vegetation. The density that is apparent from the base of the mountain does not come from a higher amount of tree density, but instead to the fact that there was an increase in the number of "large" trees at the higher elevations and those larger trees have larger canopy. Being aware of what size class of tree can be beneficial to understanding what kinds of trees can be removed if necessary for development. This information can provide the necessary insight as to make decisions regarding trail placement and conservation efforts that involve the preservation of trees that are crucial to their respective elevational location.

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