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Distribution of Dioecious Eastern Red Cedar (Juniperus virginiana) along an Environmental Gradient in Ogallala, NE.

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Disclaimer: The following thesis was produced in the Environmental Studies Program as a student senior capstone project.

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by
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Undergraduate Thesis

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Under the Supervision of Dr. Diana Pilson, Dr. Jean Knopps, and Dr. Sabrina Russo.

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Abstract

The purpose of this research was to study the sex distribution and energy allocation of dioecious Eastern Red Cedars (*Juniperus virginiana*) along an environmental resource gradient. The trees surveyed were growing in a canyon located at the University of Nebraska's Cedar Point Biological Research Station in Ogallala, Nebraska. Due to the geography of this canyon, environmental factors necessary for plant growth should vary depending on the tree's location within the canyon. These factors include water availability, sun exposure, ground slope, and soil nitrogen content, all of which are necessary for carbon acquisition.

Juniperus virginiana is a dioecious conifer. Dioecious plants maintain male and female reproductive structures on separate individuals. Therefore, proximal spatial location is essential for pollination and successful reproduction. Typically female reproductive structures are more costly and require a greater investment of carbon and nitrogen. For this reason, growth, survival and successful reproduction are more likely to be limited by environmental resources for females than for male individuals. If this is true for *Juniperus virginiana*, females should be located in more nutrient and water rich areas than males. This also assumes that females can not be reproductively successful in areas of poor environmental quality. Therefore, reproductive males should be more likely to inhabit environments with relatively lower resource availability than females. Whether the environment affects sexual determination or just limits survival of different sexes is still relatively unknown.

In order to view distribution trends along the environmental gradient, the position of the tree in the canyon transect was compared to its sex. Any trend in sex should correspond with varying environmental factors in the canyon, ie: sunlight availability, aspect, and ground slope. The individuals' allocation to growth and reproduction was quantified first by comparing trunk

diameter at six inches above ground to sex and location of the tree. The feature of energy allocation was further substantiated by comparing carbon and nitrogen content in tree leaf tissue and soil to location and sex of each individual. Carbon and nitrogen in soil indicate essential nutrient availability to the individual, while C and N in leaf tissue indicate nutrient limitation experienced by the tree.

At the conclusion of this experiment, there is modest support that survival and fecundity of females demands environments relatively richer in nutrients, than needed by males to survive and be reproductively active. Side of the canyon appeared to have an influence on diameter of trees, frequency of sex and carbon and nitrogen leaf content. While this information indicated possible trends in the relation of sex to nutrient availability, most of the environmental variables presumed responsible for the sex distribution bias differed minutely and may not have been biologically significant to tree growth.

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Acknowledgments

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Introduction

Eastern red cedar (*Juniperus virginiana*) is a common coniferous tree that has spread westward across the United States, rapidly dominating abandoned pastures and grasslands and is considered a non-native, invasive species in Nebraska (Fowells, 1965). It commonly occurs as an isolated tree in grass-dominated communities (Boyce 1954; McCaffery and Dueser, 1990). The species is so abundant that the major ecological concerns regarding red cedar are its threat to alter native grassland communities and its control and removal. The success of such a species is dependent on its ability to mate and produce seeds, the ability of the seed to colonize new areas and the juvenile's ability to survive in potentially novel environments. For these processes to occur successfully, the environment in which the plant lives must provide certain limiting factors. Such limiting factors include light availability, water, and soil nutrients.

While all terrestrial plant species require these resources, dioecious trees are unique because male and female reproductive structures are possessed by separate individuals. Therefore, the spatial distribution of sexes is key to successful reproduction. Males and female must co-habit the same area so that male pollen can reach female reproductive structures. Spatial distribution is also an important factor in establishment of juveniles. Spatial crowding creates a canopy effect which prevents germination and creates competition for light and belowground resources.

Plants express two forms of growth: vegetative and reproductive, both which require carbohydrates. In order to do so, the plant synthesizes carbohydrates from carbon, attained from atmospheric carbon dioxide, using water and sunlight in photosynthesis, which produces sugars that can then be allocated to vegetative and reproductive growth. There is a trade off between allocating carbon to vegetative growth or to reproductive structures (Kozlowski, 1971) and this trade-off is likely to be more severe when carbon assimilation is limited by the environment. However, the cost of reproduction for dioecious plant species is not equal between the sexes. In most species of dioecious plants, the cost of reproduction is higher in females than in males, as females must assimilate more carbon to produce larger seeds and fruit (Marion and Houle, 1996). Due to this need for relatively more carbon, reproductive females may be less likely than males to survive in resource poor areas (Bierzychudek and Eckhar, 1988). It is assumed that the lower cost for males to produce pollen allows them to tolerate more stressful environments than reproductive females, as males are supposed to allocate extra carbohydrates to vegetative growth, which would have gone to reproductive growth in females (Lloyd 1973). The ability to allocate more energy toward vegetative growth, allowing them to acquire more resources, makes males better competitors. Females typically experience higher mortality rates due to their relatively higher cost of reproduction, which can result in male-biased ratios in nutrient depleted environments (Meagher, 1981). Since the conditions required to survive and reproduce differ between the sexes, sex ratio and distribution should reflect environmental conditions. However, studies by Quinn and Meiners, found that sex had no effect on a Red Cedar's mortality rate and a 1:1 ratio of males to females was observed, yet this study did not include an environmental gradient (Quinn and Meiners, 2004).

Environmental gradients are typically a term used synonymously with productivity gradients, as they vary in resources required for tree growth, survival and reproduction (Adkinson and Gleeson, 2004). This study makes use of an environmental gradient provided by a canyon located at the University of Nebraska-Lincoln's Cedar Point Biological Research

Station in Ogallala, NE. The study area spans from the top of the canyon on the West, down to the valley and back up to the top of the canyon towards the East. Elements essential to growth are expected to vary largely across the canyon from West to East (Fig. 1). Sun exposure differs between the East and West sides of the canyon which may cause more desiccation on the East. Water and nutrient availability should differ based on differing angle of slopes as washing and leaching occurs.

In order to determine the environmental quality in which a tree grows, nitrogen and carbon must be quantified. Nitrogen and carbon ratios in plant tissue indicate both nutrient limitation and nitrogen saturation experienced by that individual (Tessier and Raynal, 2003). Individuals with relatively higher percentages of carbon and nitrogen in their biomass tissue likely grew in a more nutrient-rich environment than individuals expressing low nitrogen and carbon tissue content. Assuming that females demand a richer environment, the plant tissue in female individuals should have higher nutrient content than males.

Female individuals are expected to be more likely to survive and produce fruit in nutrient-rich areas than environmentally stressful areas; however sex determination of *Juniperus virginiana* is still relatively unknown. While it is likely that the species' mechanism of sex determination is genetically based (Eppley et al. 1998), one must also consider the possibility of environmental sex determination. Some species of plants may exhibit biased sex ratios under manipulation of essential resources (Guillon and Raquin, 2002). These nutrient manipulations can also induce sex change and hermaphroditism which indicates that the species is exhibiting sex determination by environmental interaction. In some populations of *Juniperus virginiana* sampled, a few individuals were found to be monoecious (Quinn and

Meiners, 2004). Clearly, there is still much information needed to fully understand the reproductive mechanisms and sex expression of this species.

The goals of this study lie in understanding *Juniperus virginiana's* dependence on environmental conditions for sex distribution and survival. This thesis will focus on how the presence of environmental nutrients, such as carbon and nitrogen, and geographic features, such as ground slope and aspect, affect the distribution of sexes. Through understanding this species' relationship between sex determination and environment, other dioecious tree species can be further explored and understood. I hypothesize that male individuals will express larger trunk diameters on average as males should be able to allocate more nutrients to vegetative growth than females. Also, the distribution of red cedars trees of different sexes will correlate with nutrient availability as indicated by carbon and nitrogen levels in soil and tissue content. I expect female individuals to grow in areas with greater levels of soil carbon and nitrogen, as well as contain more carbon and nitrogen in their leaf tissue than males.

Materials and Methods

The *Juniperus virginiana* study population is located at the Cedar Point Biological Research Station in Ogallala, Nebraska. ($41^0$12’ N, $101^0$38’ W) In order to survey the environmental variability of the canyon, six transects were established expanding from the East side of the canyon hill, down to the valley and back up to the top of the West side of the canyon using a measuring tape. The length of these transects varied between 190 to 260 meters from east to west depending on the width of the canyon at that location. Wire flags were spaced every 10 meters downhill along the transect line. Along these transects, with the wire flags serving as a center point, quadrats measuring 20 meters long by 10 meters wide were marked. Only trees growing in these quadrats were sampled.

An initial set of 987 *Juniperus virginiana* trees located in these quadrats were each given an individual number marked on red flagging tape tied to an easily accessible branch. Each red cedar tree in the initial sampling set was surveyed for location in the transect, apparent sex, aspect, trunk diameter at six inches above the ground, and slope angle of downhill incline. The feature of location is explained categorically by either East or West depending on which side of the canyon the tree was located. Location is described by meters down hill from the top of the canyon hill as a continuous variable. Sex is a categorical feature, being male, female, hermaphrodite (the individual exhibited male cones and female berries simultaneously) or juvenile (the individual was not yet reproductive). To simplify data analysis, hermaphrodites and indeterminate juveniles were eliminated before statistical analysis resulting in 964 individuals exhibiting a determined sex to be used in analysis. Aspect was a continuous variable ranging from 0 degrees (North) to 359 degrees. Slope was also a continuous variable ranging between 0 degrees (level ground) to 90 degrees (vertical). Diameter at 6 inches above ground was a response variable to the aforementioned factors.

Data compiled, the distribution of male and female trees on the east and west sides of the canyon was analyzed using a chi-square test. ANOVA (analysis of variance) was used to evaluate the effect of environmental variables on tree size This initial comparison supplied us with trees of interest which indicated a pattern of sex correlation with the aforementioned factors and from this analysis, a subset of 101 trees was selected for further data collection. This subset was selected to evenly represent the total population, including an equal amount of males and females, an equal number of individuals on both east and west sides of the canyon and a even spread of individuals growing from top to bottom of the canyon.

101 trees in this subset were tagged with their respective numbers with more permanent aluminum tags. Data collected from these included a soil and plant tissue sample. Using a soil auger, a 2 x 10 cm volume of soil (excluding litter) was taken from each cardinal direction under the canopy of the tree. The four samples were homogenized and kept in a labeled paper bag. Randomly selected twigs were cut off of each tree and kept in labeled paper bags. Upon return to the laboratory, the soil and tissue samples were dried in a drying cabinet at 65 degrees Celsius. The soil samples were sifted for purity using a 2mm sieve and then sorted by hand until the sample was free of non-soil material. The plant tissue was separated by hand so that only microphyll needle tissue would be used for the determination of Carbon and Nitrogen concentration. The soil and leaf tissue samples were then pulverized using coffee grinders (Braun KSM2-WH) and a plant tissue grinder respectively. The pulverized samples were stored in individually marked plastic vials for future use. Soil and biomass samples were packed into tin cups to quantify their Carbon and Nitrogen contents using the Costech

Analytical ECS 4010 Elemental CHNSO Combustion Analyzer in the Ecosystems Analysis Lab at the University of Nebraska. Using a microbalance scale, between 3 to 3.5 mg of dried pulverized leaf tissue and between 20 to 25 mg of soil were packed and processed. The Elemental Analyzer used a furnace to destroy the tin cups in which the samples were held and then vaporized the samples of interest. These vapors were then analyzed by the machine to determine what percentage of that sample was carbon and nitrogen.

The results of the carbon and nitrogen ratios in the soil and leaf tissue were analyzed with a general linear model and then compared back to the original environmental qualities and sex of the tree. With the aforementioned data compiled, we hope to learn more about the sexual distribution of *Juniperus virginiana* as it relates to nutrient availability and cost of reproduction.

Statistical Analysis

We used ANOVA to analyze the relationship of environmental factors (aspect, slope, meters down canyon, sex, side of canyon, transect, aspect*sex, slope*sex, meters down canyon*sex, side*sex, and transect*sex) to diameter of tree trunks. Distribution of sex in relation to side of the canyon was analyzed using a chi-square test. Regarding the subset trees, percentages of carbon and nitrogen in leaf tissue and rooting soil was analyzed using a general linear model. Comparisons about relationships between response and explanatory variables were represented in graphs using the general linear model.

Results

Variation in Diameter Along an Environmental Gradient in Relation to Sex

After comparing all categorical and continuous environmental variables, dependent variables and sex, the most significant comparisons (resulting in the largest F values) included aspect, transect and side*sex. From this data analysis, it would appear that those features have the greatest influence on the tree's energy allocation to growth in width (Table 1). Note that aspect and side are confounded in the respect that these features differed conjointly and represent the same changes in environmental location. In relation to diameter, transect 1 had the largest mean diameter at 25cm while transect 3 has the smallest mean diameter at 18.8cm (Fig. 2). Neither sex nor side appeared to affect the diameter solely, however there appeared to be an interaction between side*sex with the diameter. Female trees on the West had a larger mean diameter than females on the East. Conversely, male trees on the West had a smaller mean diameter than males on the East (Fig. 3). However, while this data does suggest to possible trends in relation to tree growth, the trees have not been aged.

Distribution of Sexes Along an Environmental Gradient

Distribution of sex appeared to be biased based on side of the canyon. Of the 964 sexually determined individual Red Cedars, 45.95% were females and 54.05% were male. Of the 443 females, 51.01% were located on the East side of the Canyon and 48.99% were located on the West. Of the 521 males, 44.91% were located on the East and 55.09% on the West (Fig. 4A). From this data, it appears that the sexes grew relatively equally on the East side of the canyon, but the West side of the canyon was dominated by males relative to females. The slopes of these hills were also considered because nutrients and water leach from steep slopes more quickly than flat surfaces (Fig. 4D). While it was a weak difference, the mean slope of the hill side was steeper on the West side than the East (Fig. 4C).

<u>Variation in Leaf Nutrients of Each Sex Along an Environmental Gradient</u>

The subset of 101 representative individuals added a new dimension to understanding the local environment and nutrient availability of each individual tree. The percentage of carbon and nitrogen in soil of the tree's immediate rooting zone indicated availability of these nutrients to be used by the individual. The percentage of carbon and nitrogen in the tree's leaf tissue indicated nutrients present in the vegetative growth of the individual.

Regarding nitrogen levels in leaf tissue: considering sex in relation to nitrogen in the total surveyed population, female leaf biomass contained higher levels of nitrogen than males, while the few hermaphrodites contained even less nitrogen (Fig. 5A). In respect to location, the average level of leaf tissue nitrogen was slightly higher among individuals on the east side of the canyon than the west (Fig. 6A). When sex and location are considered simultaneously, female individuals on the East contained higher levels of nitrogen than females on the West or Males on the East. Males on the West side contained higher levels of nitrogen than males on the East or females on the West (Fig. 7A).

Regarding carbon levels in leaf tissue: among all trees surveyed, Males contained higher levels of carbon in leaf tissue than females. The few possible hermaphrodite leaf tissue samples contained the most carbon relative to males and females (Fig. 5B). Considering location, on average individuals growing on the East side of the Canyon contained slightly more leaf tissue carbon than those on the West (Fig. 6B). When considering sex and location simultaneously, both males and females contained higher percentages of leaf tissue carbon on the East side of the canyon than on the West (Fig. 7B).

The last analysis of leaf tissue was the ratio of carbon to nitrogen. Among the entire surveyed population, the few hermaphrodites resulted in the highest ratio of carbon to nitrogen, then males and females had the smallest carbon to nitrogen ratio in leaf tissue (Fig. 5C). Throughout the entire population, individuals on the West side had a higher carbon to nitrogen ratio than those on the East

(Fig. 6B). In the relationship between sex and side of the canyon, males on the east had a higher C to N ratio than males on the West. Conversely, females on the East had a lower C to N ratio than those on the West (Fig. 7C).

Variation in Soil Nutrients of Each Sex Along an Environmental Gradient

The percentage of carbon and nitrogen content in rooting soil indicates environmental nutrient availability of these elements. There was little to no difference in soil content between sexes and sides of the canyon. Regarding percentages of nitrogen in soil: minor differences in average level of soil nitrogen existed between the sexes. Male trees typically grew in soils with slightly higher nitrogen content (Fig. 8A). In relation to side of the canyon, the East and West sides experienced nearly identical averages of soil nitrogen (Fig. 9A). Regarding the relationship between sex and side of the canyon, males on the East experienced the highest nitrogen soil levels and females on the West experienced the lowest (Fig. 10A). However, the difference was minor and not likely biologically significant to the tree's growth.

Regarding percentages of carbon in the soil: in relation to sex, males grew in areas with higher carbon levels, slightly lower were hermaphrodites and females grew under the lowest average soil carbon contents (Fig. 8B). In relation to side, the East side of the canyon had a slightly higher average level of soil carbon than the West (Fig. 9B). Regarding the relationship of sex with side of canyon, males on the East experienced the highest level of soil carbon and females on the West experienced the lowest soil carbon levels (Fig. 10B).

The ratio of carbon to nitrogen in soil did not significantly differ between sexes (Fig. 8C). In relation to side of the canyon, the East side had slightly higher soil C/N ratio than the West (Fig. 9B). In the relationship between sex and side of the canyon, males on the East had the highest C/N ratio and males on the West had the lowest (Fig. 10C). However, the difference is not likely biologically significant to the tree.

Discussion

Main Results

In accordance with my hypothesis, higher nitrogen content in leaf tissue and lower carbon to nitrogen ratios were observed in female trees than males on average. However, the location along the environmental gradient, and side of the canyon had an important influence on sex ratio and leaf nutrient content. Two trends of importance were observed in the data collected from the initial set of 987 trees. First, location on the gradient affected trunk diameter six inches above the ground. Also, the affect of sex on diameter appeared to be dependent on side of the canyon. Second, there appeared to be a bias of sex distribution dependent on side of canyon. The results of these observations provide weak support for the hypothesis that female trees are distributed at a higher frequency in nutrient rich environments than males, but more importantly, created new questions for research on this topic.

Variation in Diameter Along Gradient in Relation to Sex

First, female trees on the West had a larger mean diameter than females on the East. Yet, male trees on the West had a smaller mean diameter than males on the East. On the surface, this data indicates that females can allocate more energy to vegetative growth if under less environmentally stressful conditions, assuming the West side was not as desiccating an environment as the East due to less harsh daily sunlight exposure. The fact that males had a larger mean diameter on the East side than females supports the notion that females would be struggling to allocate energy to vegetative growth under stressful conditions. I am unsure why males would have smaller mean diameters on the West, relative to females on the West and males on the East. One explanation could be intraspecific or intrasex competition as this collection of data did not consider spatial crowding, which is another limiting force on vegetative growth. Also it is important to note that these trees have not yet been aged. Analyzing size without the age or growth rate of the tree is a misleading and inaccurate measure of growth.

Distribution of Sexes Along Environmental Gradient

The initial collection of data provided a representation of sex distribution, which appeared to be biased depending on which side of the canyon the tree was growing on. From the distribution patterns of the initial 987 trees, it appears that the sexes occurred with relatively equal frequency on the East side of the canyon, showing a slight preference for females on the East relative to the West. However, the West side of the canyon was dominated by males. This raises the question of which of these initially sampled factors may differ dramatically between the two sides and thus impact this biased distribution of sexes. Factors differing between the East and West include aspect/sun exposure and ground slope (Fig. 1). While no techniques were used to measure sun exposure accurately, it is assumed that the East side of the canyon would be a more desiccating environment. This is because the East side would receive intense afternoon and evening sunlight and be shaded from the early morning sun. The West side of the canyon would receive primarily morning and early afternoon sunlight and be shaded as the sun descends. No methods of measuring water availability were implemented, but it is assumed that the West side of the canyon would be a less desiccating environment than the East.

Based on the hypothesis, one would predict that the West side would be dominated by females as the growth and survival of females would be less limited in a less desiccating environment (Tweddle, 2003). This hypothesis was not supported by the actual distribution of individuals. In fact the results were the contrary: females were more numerous on the East side and males dominated the West side. Perhaps this distribution could be explained by nutrient leaching, as the angle of ground slope was slightly steeper on the West side than the East side of the canyon (Rastetter, 2004.,Ostendorf and Reynolds, 1993). The distribution of individuals in regard to the slope supports the notion that males are more populous than females under more stressful conditions as the steeper incline on the West side was dominated by males while the flatter East side contained more females. However, the difference in slope is not drastically different between the two hill sides in relation to potential effects on nutrient leaching. It is also possible that if male trees can allocate more energy to vegetative growth, thus growing taller quicker, they could out-compete females in the environment resulting in the same biased distribution.

Variation in Leaf Nutrients of Each Sex Along an Environmental Gradient

The data collected from the subset of trees provided us with better information about the individual environmental conditions and of the trees, nitrogen and carbon ratios were quantified in both in plant tissue and soil. Relatively higher levels of N and C in plant tissue are indicative of the plant's access to nutrients and ability to assimilate those elements to energy for vegetative growth (Tessier and Raynal, 2003). The percentage of nitrogen in plant tissue was only slightly higher in females than males, hardly a significant difference. There was a larger disparity between males and females regarding the percentage of carbon in leaf tissue, with males possessing more carbon. This increase of leaf carbon content indicates the ability of males to allocate more C to their leaves, which may be used in carbon-based herbivory defenses (Bryant, 1983).

A small difference between the average presence of N and C in leaf tissue existed depending on side of the canyon. Individuals on the East exhibited more N and C in their leaf tissue than trees on the West. As expected, this may be due to nutrient limitation due to a relatively steeper slope on the West side. Nitrogen levels in females were higher on East than females on the West, possibly a repercussion of slope and nutrient leaching. Conversely, the percentage of N in males was higher on the West than in males on the East. This could explained as an effect of crowding as growth on the West side was less dense (0.054 trees per unit area) than the East (0.075 trees per unit area).

Variation in Soil Nutrients of Each Sex Along an Environmental Gradient

Higher levels of N and C in the soil are indicative of a nutrient rich environment. According to my hypothesis, I expected females to be present under higher levels of soil nutrients. This hypothesis was not supported by the observations. The levels of carbon and nitrogen in the soil did not differ greatly enough between the sexes or sides of the canyon to be considered biologically significant to growth. Therefore, soil did not play a role in affecting sex ratios and distribution.

Conclusion

There is modest support that survival and fecundity of females demands environments relatively richer in nutrients, than needed by males to survive and be reproductively active. However, most of the environmental variables presumed responsible for the sex distribution bias expressed very little difference between the sexes and side of the canyon. These minor differences between environmental factors may not be biologically significant to the growth or survival of the tree. In order to gain a more accurate understanding of the influence of environmental factors on the sex distribution of *Juniperus virginiana*, several causes of error and inconsistencies must be addressed: the problem of using ecological field surveys, the sampling size and lack of information about the trees.

In future application of this research, it would be beneficial to use a controlled experiment in which nutrients, growth and sex expression could be more closely monitored and more drastically manipulated. Trends would be more apparent with a larger sampling survey of manipulated trees. Also, more concrete data could be gained from quarterly inspections of each tree. The temporal difference in sex expression may have caused misidentification of sex of some individuals. One individual in our plot clearly exhibited both male cones and female berries on the same twig. This is indicative of hermaphroditic tendencies or the ability of individuals to change sex. Finally, this study would benefit from more refined quantifications about the individual trees and their immediate environments. It is essential that each tree be cored and aged. A better system of quantifying water availability and sun stress would solidify or reject assumptions about environmental qualities between the two sides of the canyon. Most importantly, it appears the side of the canyon has the most affect on other variable factors. Therefore, future application of this study should focus of differences between the East and West side of the canyon and causation of those discrepancies.

Figures and Graphs

Table. 1

The SAS System

The GLM Procedure

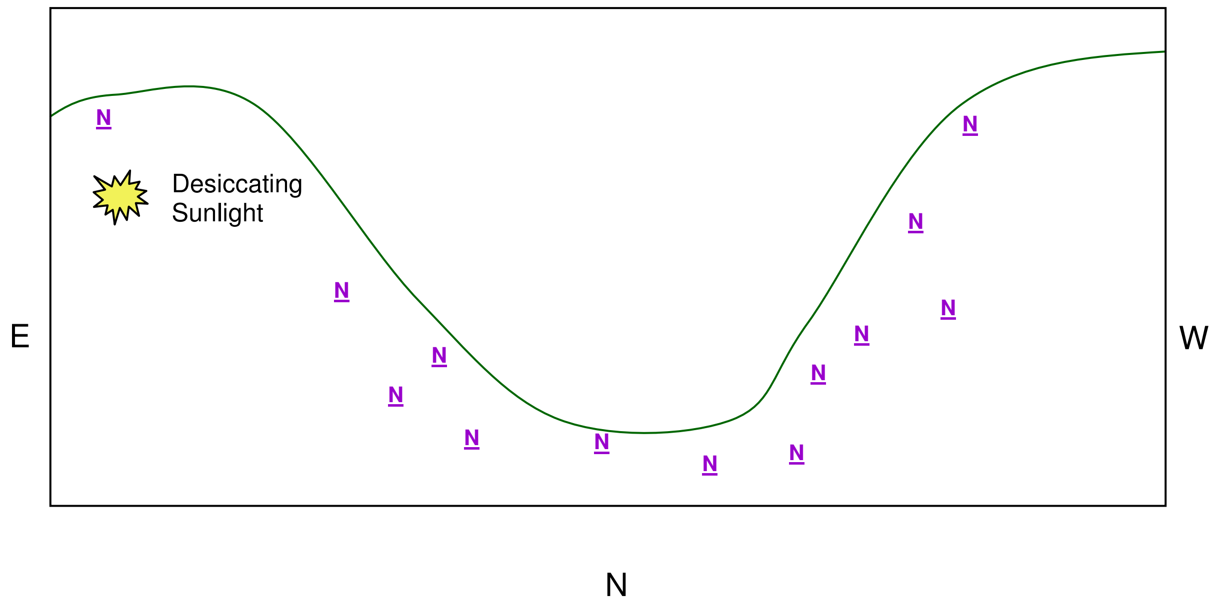
Dependent Variable: Diameter at 6 inches above ground

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	16543.9315	870.7332	3.62	<.0001
Error	944	226927.0154	240.3888		
Corrected Total	963	243470.9469			

R- Square	Coeff Var	Root MSE	Diameter Mean
0.06795	72.85797	15.50448	21.28041

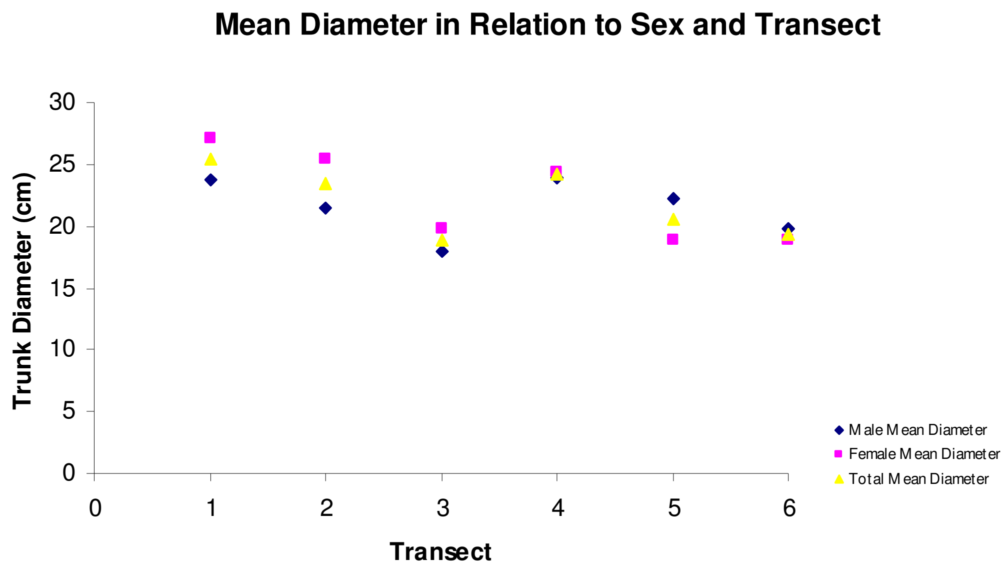
Source	DF	Type III SS	Mean Square	F Value	Pr > F
aspect	1	2347.235293	2347.235293	9.76	0.0018
slope	1	488.191812	488.191812	2.03	0.1545
metersdown	1	467.30452	467.30452	1.94	0.1636
sex	1	28.305841	28.305841	0.12	0.7316
side	1	11.449514	11.449514	0.05	0.8273
transect	5	5700.655214	1140.131043	4.74	0.0003
aspect*sex	1	120.801328	120.801328	0.5	0.4786
slope*sex	1	12.902221	12.902221	0.05	0.8168
metersdown*sex	1	157.495667	157.495667	0.66	0.4185
side*sex	1	1958.789882	1958.789882	8.15	0.0044
transect*sex	5	1472.574051	294.51481	1.23	0.2951

Fig. 1



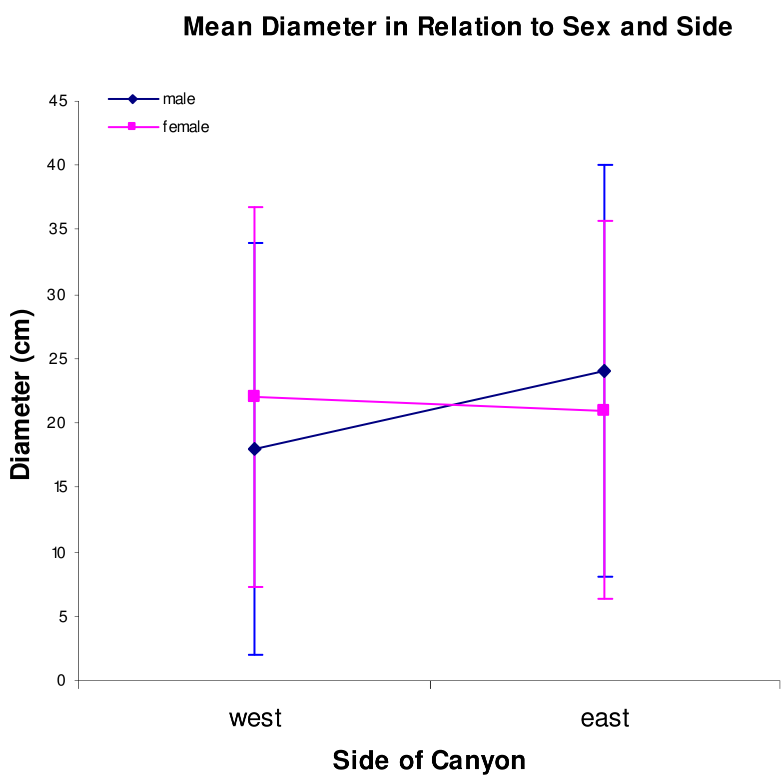
The Cedar Point Canyon gradient is assumed to differ in sunlight exposure and nutrient availability depending on location in the Canyon. Nitrogen and water are assumed to leach to the bottom of the canyon. The East side is assumed to be a more desiccating environment due to afternoon sun exposure.

Fig. 2



Mean Diameter in Relation to Sex and Transect
Trunk Diameter (cm)
30
25
20
15
10
5
0
0
1
2
3
4
5
6
Transect
Male Mean Diameter
Female Mean Diameter
Total Mean Diameter

Fig. 3



Mean Diameter in Relation to Sex and Side
male
female
45
40
35
30
25
20
15
10
5
0
Diameter (cm)
west
east
Side of Canyon

Fig. 4A

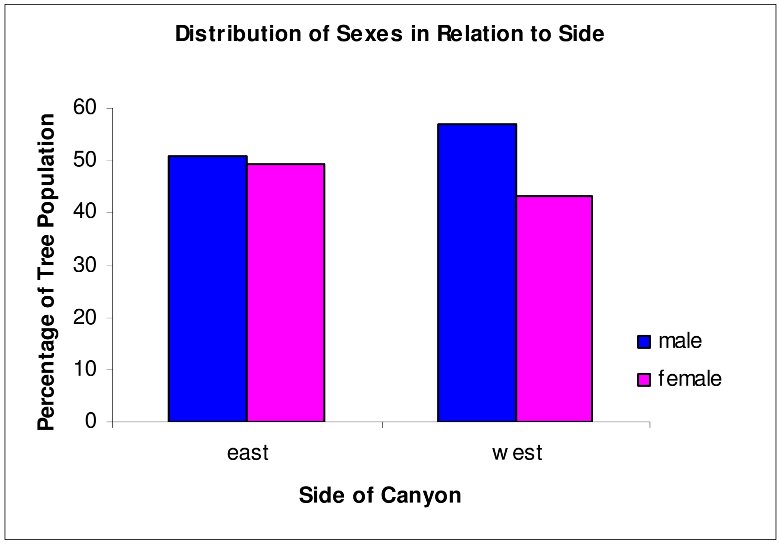

Distribution of Sexes in Relation to Side
Percentage of Tree Population
60
50
40
30
20
10
0
east
w est
Side of Canyon
male
f emale

Fig. 4B

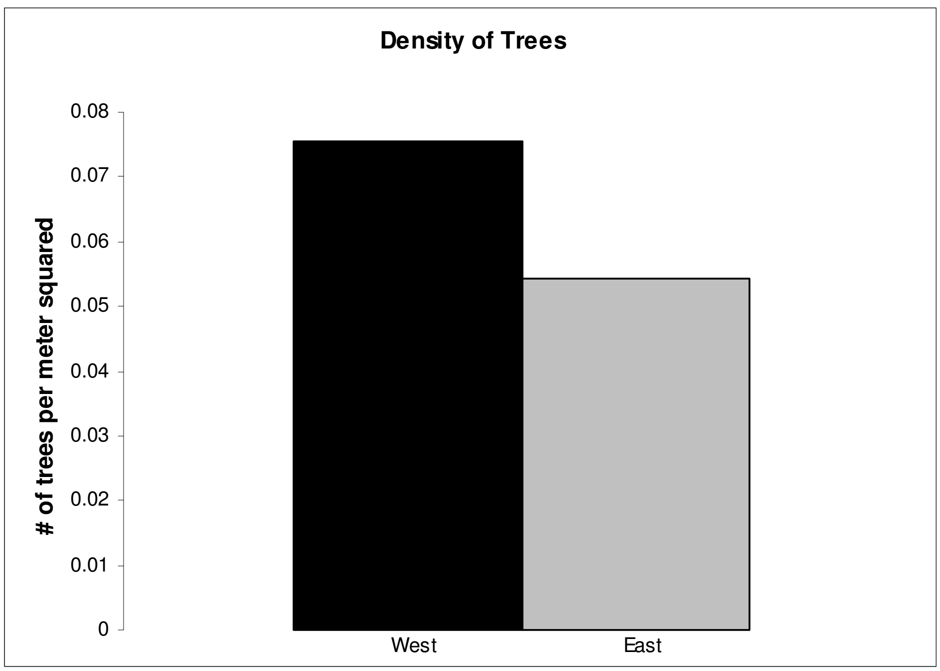
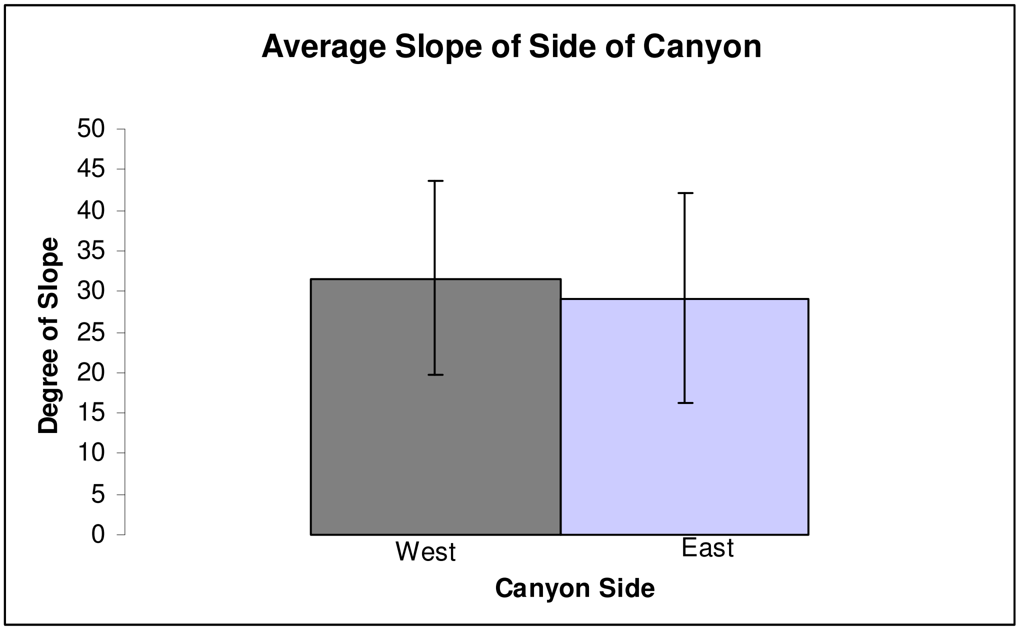
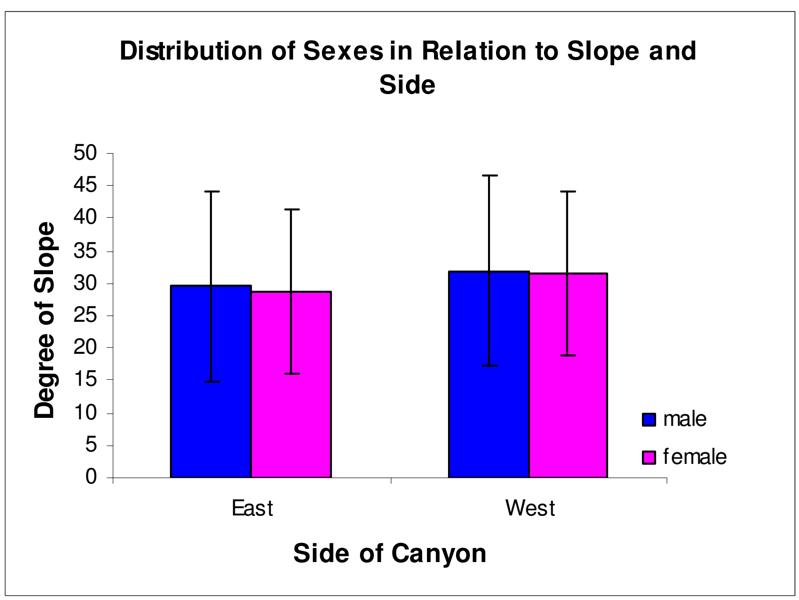

Density of Trees
# of trees per meter squared
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
West
East

Fig. 4C



Average Slope of Side of Canyon
Degree of Slope
50
45
40
35
30
25
20
15
10
5
0
West
East
Canyon Side

Fig. 4D



Distribution of Sexes in Relation to Slope and Side
Degree of Slope
50
45
40
35
30
25
20
15
10
5
0
East
West
Side of Canyon
male
female

Fig. 5A

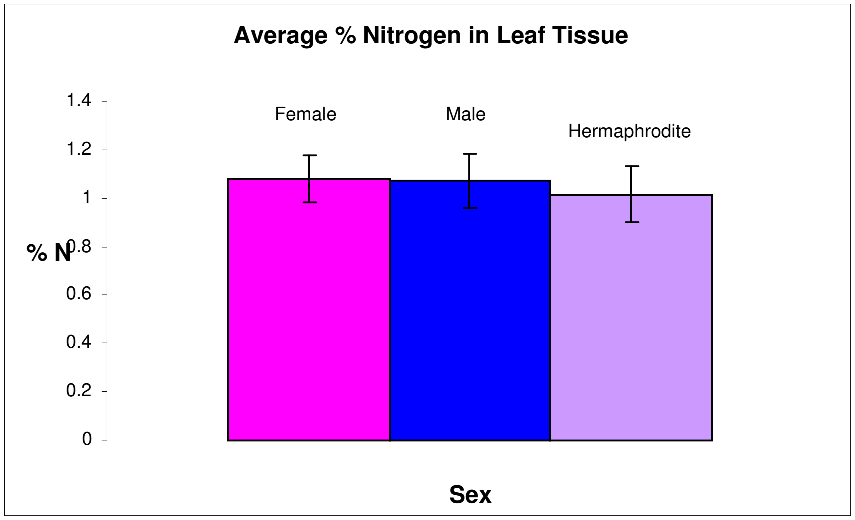


Fig. 5B

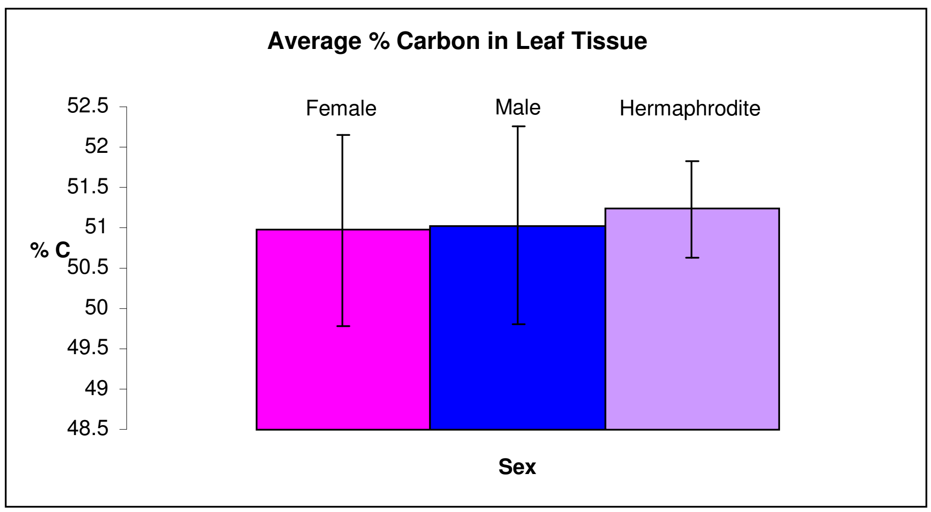


Fig. 5C

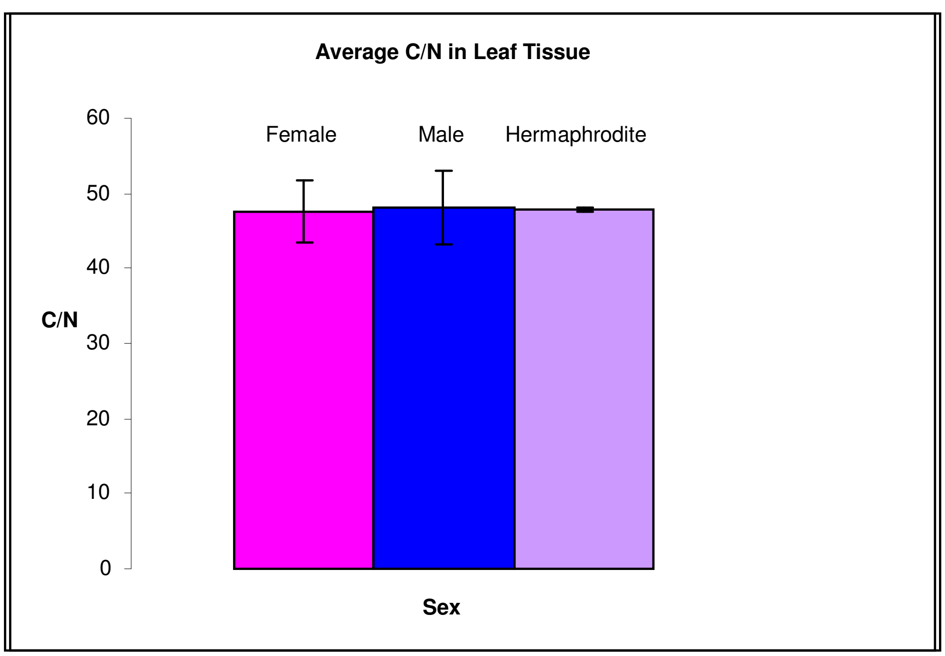


Fig. 6A

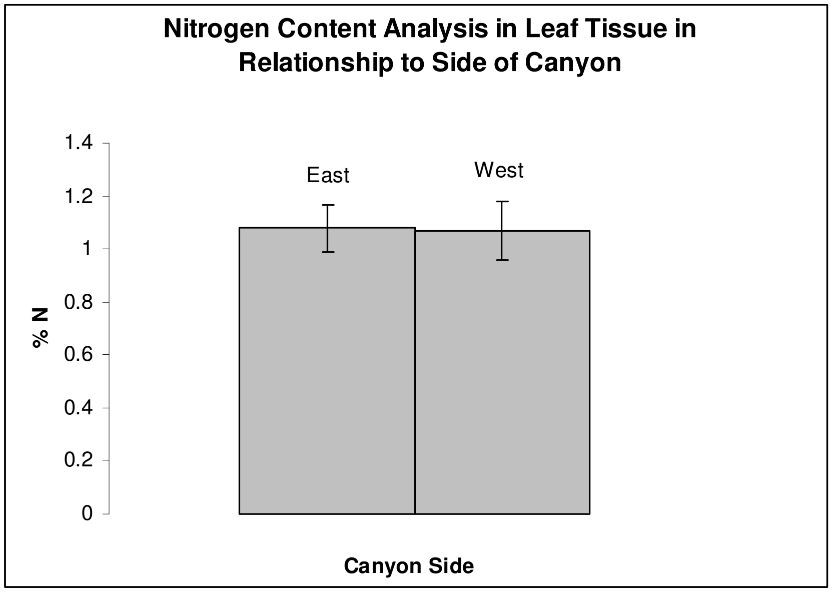

Nitrogen Content Analysis in Leaf Tissue in Relationship to Side of Canyon
1.4
1.2
1
0.8
0.6
0.4
0.2
0
% N
East
West
Canyon Side

Fig. 6B

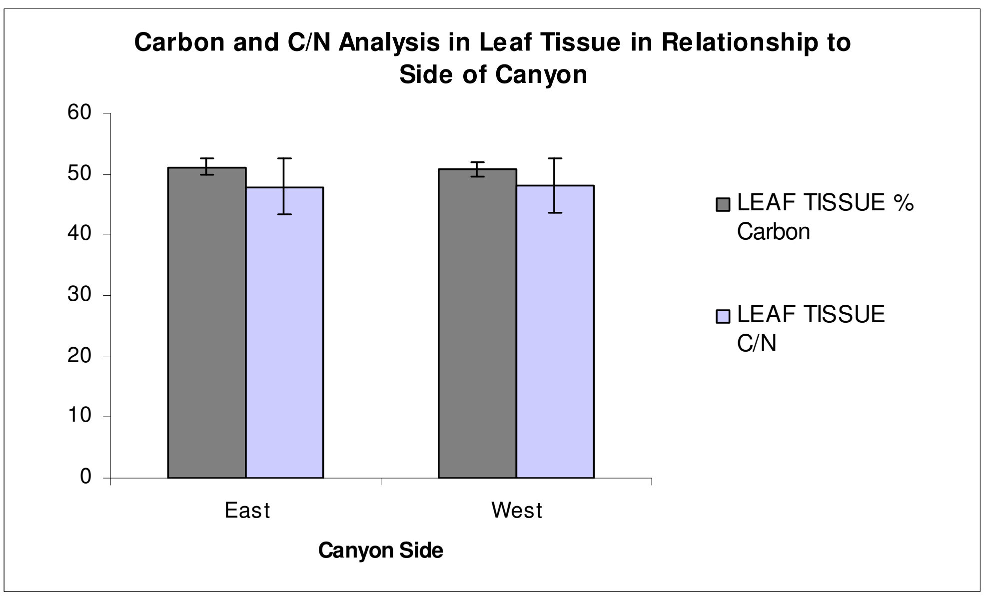

Carbon and C/N Analysis in Leaf Tissue in Relationship to Side of Canyon
60
50
40
30
20
10
0
East
West
Canyon Side
LEAF TISSUE % Carbon
LEAF TISSUE C/N

Fig. 7A


Relationship of % Nitrogen in Leaf Tissue to Sex and Side of Canyon
1.4
1.2
1
0.8
0.6
0.4
0.2
0
%N
East
West
Canyon Side
Male
Female

Fig. 7B

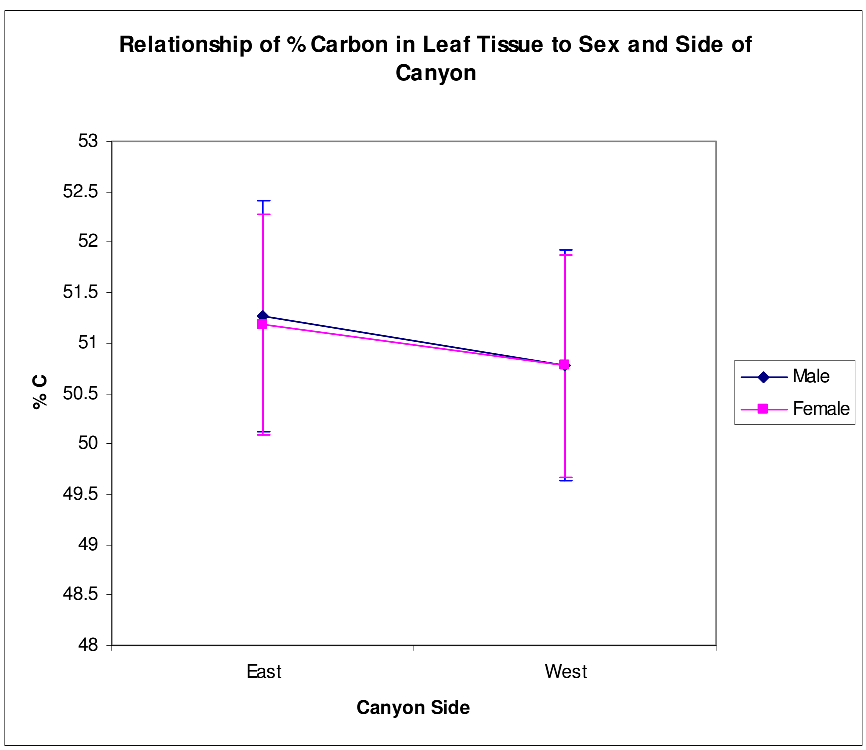
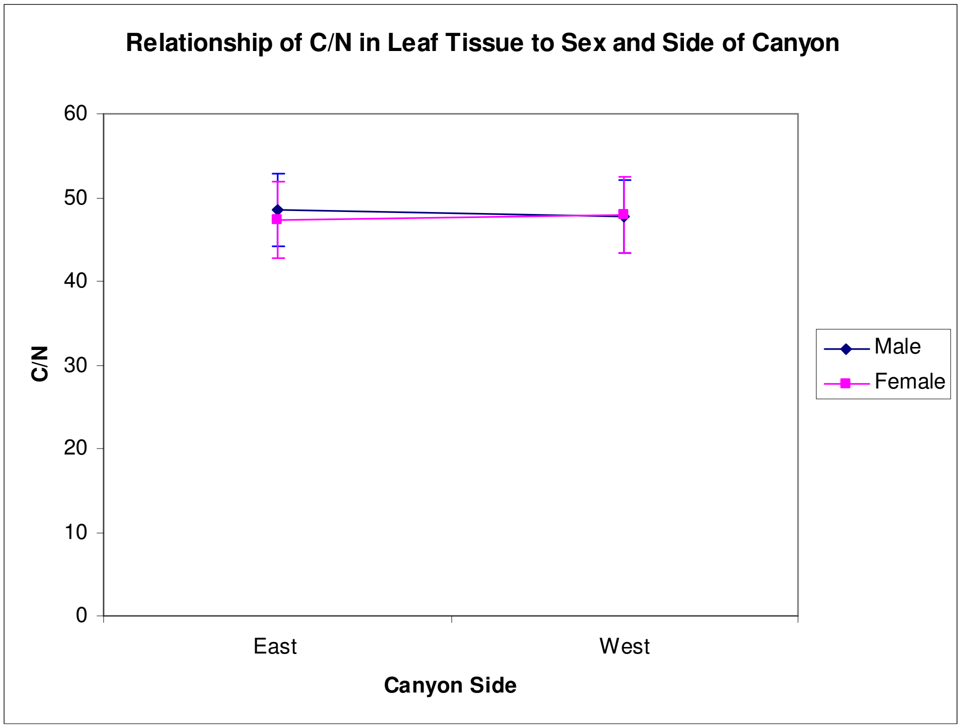

Relationship of % Carbon in Leaf Tissue to Sex and Side of Canyon
53
52.5
52
51.5
51
50.5
50
49.5
49
48.5
48
% C
East
West
Canyon Side
Male
Female

Fig. 7C



Relationship of C/N in Leaf Tissue to Sex and Side of Canyon
60
50
40
30
20
10
0
C/N
East
West
Canyon Side
Male
Female

Fig. 8A

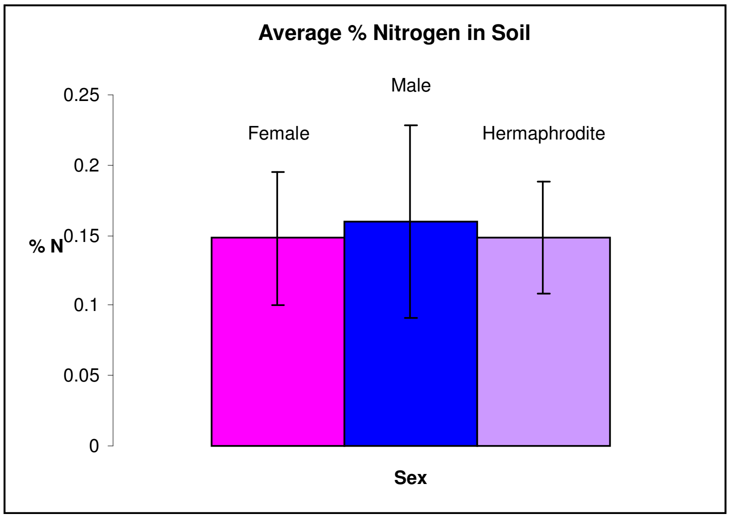


Fig. 8B

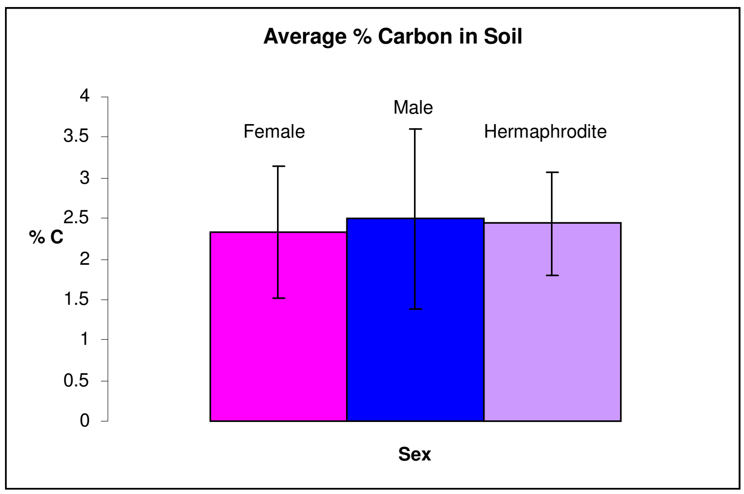


Fig. 8C

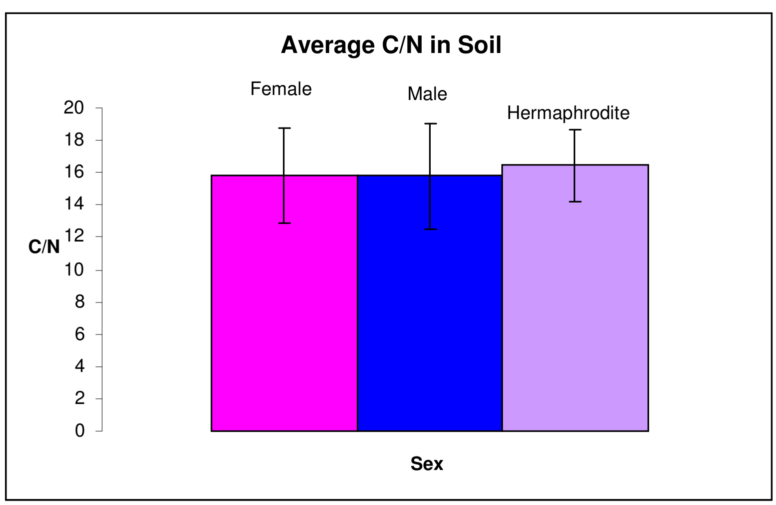
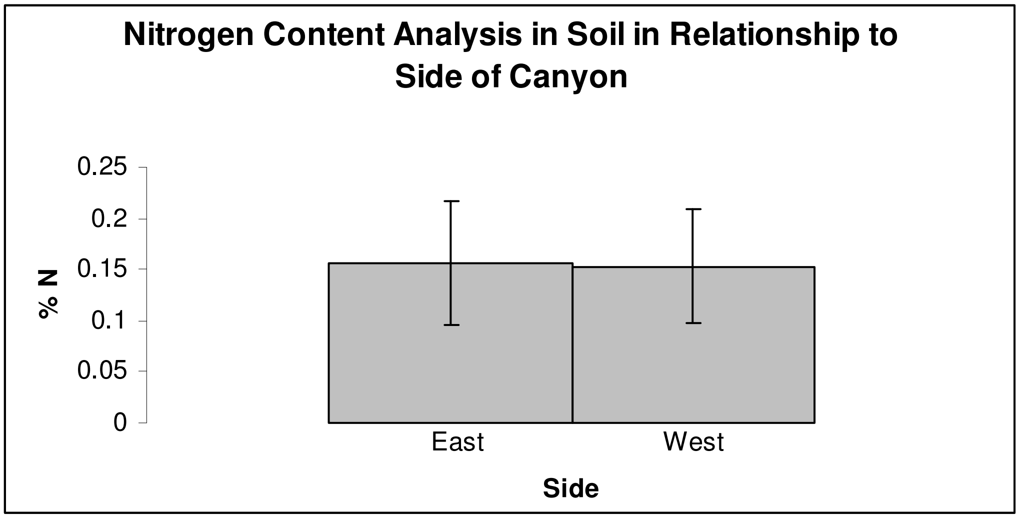
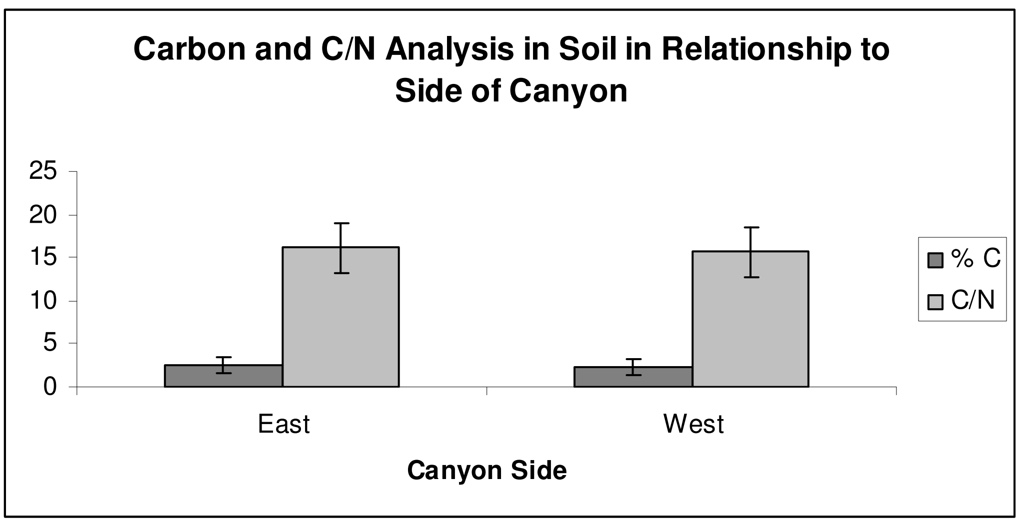


Fig. 9A



Nitrogen Content Analysis in Soil in Relationship to Side of Canyon
0.25
0.2
0.15
0.1
0.05
0
% N
East
West
Side

Fig. 9B



Carbon and C/N Analysis in Soil in Relationship to Side of Canyon
25
20
15
10
5
0
East
West
Canyon Side
% C
C/N

Fig. 10A

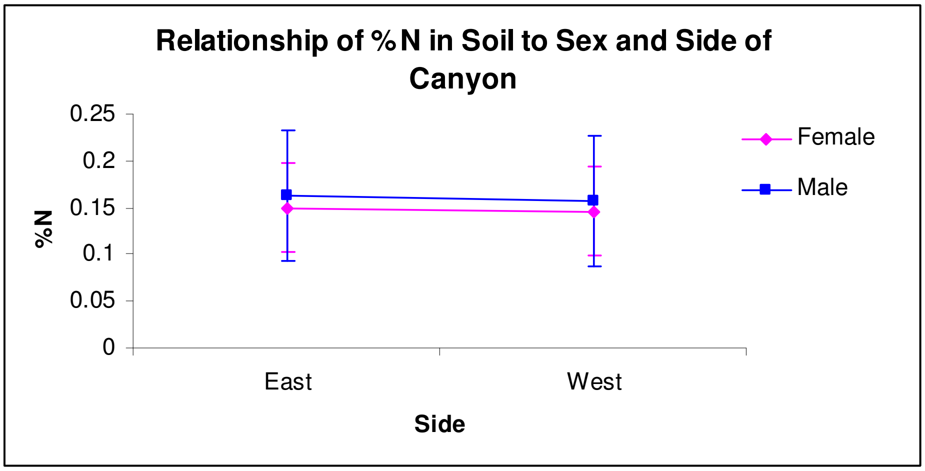


Fig. 10B

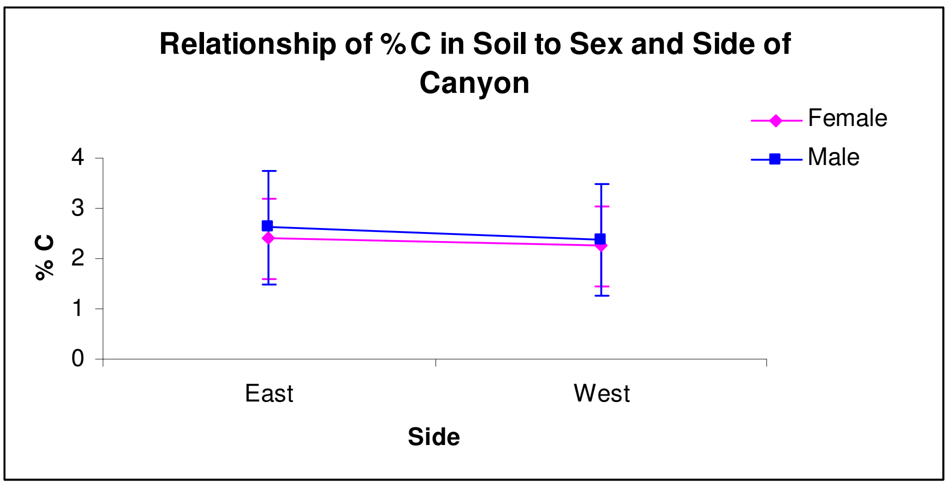
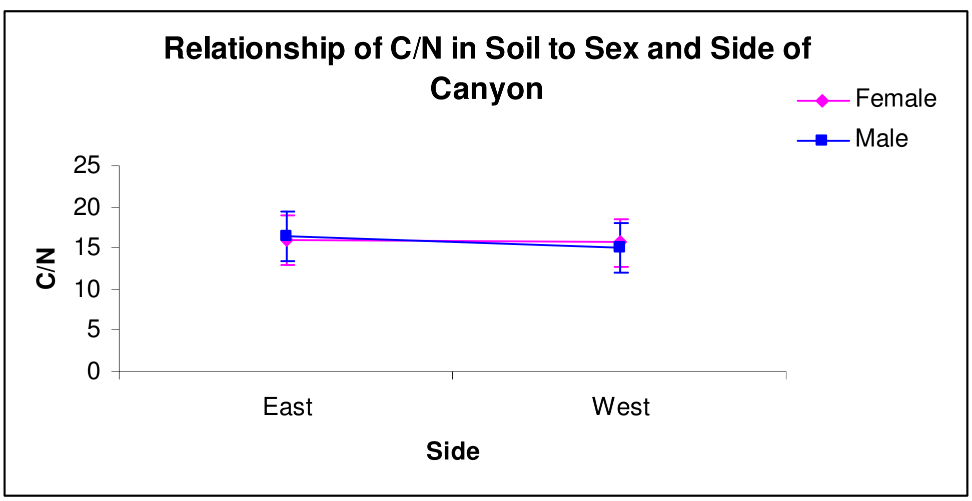


Fig. 10C



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