The Human Presence of the University of Michigan Biological Station and the Growth of *Acer saccharum*

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Abstract

With humans building new cities, roads, and public transportation projects, we are disturbing habitats around the world. To study the effect human actions have on these habitats, we used the University of Michigan Biological Station (UMBS) as a model. Although UMBS was established to study biological and ecological processes uninhibited in nature, there is a very real possibility that our actions from building and living at UMBS have left a tangible mark on the surrounding environment. To test whether our presence here has a significant effect, we chose *Acer saccharum*, or Sugar Maple, as our model plant species. We identified several perturbations linked to human actions such as vegetation removal, transportation, building developments and agricultural uses. These variables were measurable by testing for soil density, soil moisture, soil nutrient levels (nitrate, phosphate, ammonium), light intensity, and total neighboring tree biomass. We found that there was a significant difference in average annual tree growth between two test sites: on and off-campus. The trees off-campus had a higher average annual growth rate than the trees on-campus. All of the variables excluding phosphate levels were significantly different between both test sites. The results we obtained can be explained partly by differing levels of soil density which could have reduced soil moisture and thus affect tree growth. The difference in nutrient levels could be due to the human action of clearing out trees at UMBS to build cabins, research laboratories, and other buildings as well as the constant removal of leaf litter on-campus grounds. Our findings can be applied to help UMBS in future landscape architecture decisions, or even be applied to larger cities to ensure that they are doing as much as possible to minimize adverse disturbances to flora, fauna, and ecological processes related to human actions.

Introduction

Many scientists agree we are currently in the midst of the sixth mass extinction. However, unlike past extinctions that were caused by natural occurrences such as volcanic eruptions and asteroids, the present crisis is almost entirely caused by us, the human species (Wake & Vredenburg, 2008). Mammalian extinctions were relatively rare before humans' exponential growth started around 500 million years ago (Prautorius, 2011). A worldwide assessment shows that one-third or more of the 6,300 species are threatened with extinction (Wake & Vredenburg, 2008). The most damaging of these activities include habitat destruction, climate change, introduction of invasive species, and overexploitation. Habitat destruction, however, poses the largest threat for biodiversity loss (D. Karowe, personal communication). Humans have impacted roughly 75% of the Earth's total land surface and the repercussions of these impacts are only recently being realized and understood (UNEP 2002). It is our overwhelming presence and impacts that have caused the vast majority of recent extinctions and destruction on Earth.

Habitat destruction continues to harm Earth's biodiversity under the veil of development. Urbanization pushes city boundaries further and further into bordering terrain, replacing rich microfauna with houses, strip malls and eight-lane highways. By the end of the century, "the urban-suburban population had more than doubled, yet the area occupied by that population almost quintupled" (Mitchell). Enormous single-family houses grow ever larger. "American homes are now over twice the size of European homes" and yet it seems we still have not caught up with the Joneses (Orphan Road 2011). Suburbs sprawl into the countryside. Small towns become small cities, small cities become large cities; forest becomes farmland, farmland becomes concrete. Of course, accommodating a growing population is necessary, and to do so, urban infrastructure must inevitably expand. But current land-use practices and management techniques are inappropriate for the reality of our changing environment. Sprawl is now claiming farmland, forest, and other undeveloped land at a rate of two millions acres a year (Mitchell). This means increased energy use for heating and appliances, more waste production, fuel consumption, and a greater effect of urban heat islands. Not to mention other harder to quantify environmental damages such as the loss of ecosystem services, habitat destruction, industrial chemical runoff, water table depletion, flood and storm control, and soil erosion. Urbanization is a fact of the 21st century; it is crucial to understand how we can mitigate the effects of cities and towns of every size.

According to the CIA World Fact Book (2012), approximately 50% of the world's population lives in rural, small community settings. From a study in 2005, there are approximately 3 billion citizens in rural areas and towns, a statistic that has doubled from 1950 (Anriquez & Stloukal, 2008). Additionally, many people are finding themselves in the periphery of cities in small towns and communities, which is very common in cities of South Africa, for example (U-N Habitat, 2010). For the purpose of our research, we are identifying small communities as those with a population less than 1000 people, and detached from any larger cities. However, regardless of our constraints, both rural communities and the peripheries of cities still inflict serious stress on the environment. These smaller scale impacts, such as the compaction of soil as a result of foot and vehicular traffic and the removal of fallen leaf litter can have major consequences on ecological processes. One study that focused on the effects of human induced soil compaction found that in Indian agricultural communities that had corn growing in soils with major soil compaction (due to human presence or mechanized farming methods) had a significant decrease in the amount of corn produced (Bhadoria, 1986). Another analysis of soil compaction on wheat farms found that even moderate soil compaction hurt the yield under dry conditions (DeJong-Hughes, Moncrief, Voorhees, & Swan, 2001). Similar studies on other crops found comparable results. If soil compaction can reduce crop yield, then it may reduce tree growth in the vicinity of towns and human communities.

Human impacts can be defined as transportation, agricultural use, landscaping that clears vegetation, and infrastructure development (this includes sidewalks, roads, buildings, and other constructions).To look at the larger picture of human impact, our team scaled down the magnitude of interactions with a focus on a small, seasonal community- The University of Michigan Biological Station (UMBS) in Pellston, Michigan. The population of UMBS is between 200-400, well within our 'small community' parameters. Our location at UMBS provided us with the opportunity to study the impact of human presence on the growth of surrounding trees, the first step in ascertaining our impacts on the surrounding ecology. A distinct target tree species was chosen, *Acer saccharum*.

Acer saccharum was selected for its' abundance across UMBS property, as well in Northern Michigan where "sugar maple-beech-yellow birch" and "beech-sugar maple" forest cover types are common (Smallidge). Tree growth is dependent on the type of soil it is rooted in (Smallidge). Therefore, to standardize our experiment we chose trees located consistently on rubicon sandy soil across UMBS property. With regards to our study, the consistency of this soil associated with *A. saccharum* at UMBS provided the necessary standardization to compare soil moisture, nutrients and densities in areas with varying human interactions. A contributor to soil nutrient levels is fallen leaf litter that decomposes and enriches the soil overtime (Demchik, 1998). Despite its importance to nutrient levels, the UMBS maintenance staff removes leaf litter on-campus every Spring. Therefore, varying degrees of leaf litter between the on-campus and off-campus areas might correlate with tree growth. A final variable characteristic of *A. saccharum* is shade tolerance. *Acer saccharum* trees can remain "suppressed as juveniles in the understory" of forests until a gap in the canopy presents an opportunity for direct sunlight and subsequent rapid growth (Smallidge). Consequently, varying light intensities on- and off-campus could affect tree growth. We wanted to look for a difference in tree growth between more available direct sunlight on the open UMBS campus and the shaded, denser, forested area off-campus.

This information enabled our team to narrow our inquiry about human impacts by focusing on the tree species *A. saccharum* and using UMBS as an embodiment of a small community's impacts on tree growth. This was relevant in providing a proxy for understanding similar perturbations in other areas around the world.

Our team formulated the following null and alternative hypothesis to delve into the question of human impacts on their surrounding environment:

Ho - Human presence within UMBS has no impact on the growth of the *A. saccharum* tree species.

Ha- Human presence within UMBS impacts the growth of the *A. saccharum* tree species.

To test our hypothesis, we looked at how the growth of this tree species was impacted by humans. We hypothesised that our impacts would influence the growth of *A. saccharum.* We tested soil moisture, soil density, soil nutrients (ammonium, nitrate, phosphorous), biomass of neighboring trees, and sunlight intensity at two test sites with similar conditions but varying levels of human disturbances. The soil variables were chosen because we presumed that the soil compaction due to infrastructure development and transportation could affect the tree roots' ability to expand and retain moisture and nutrients. We chose to test total neighboring biomass because we expected trees on-campus to have less competition for similar resources, and perhaps grow more because of that. In that same vein, sunlight intensity was chosen because the clearing, selective planting, and general landscaping of trees on-campus seemed relevant to the amount of sunlight trees could receive and convert into energy for growth.

An on-campus and off-campus test site within UMBS property were chosen to provide a comparison for growth of *A. saccharum*, the latter providing an area with an absence of constant human activity.

Materials and Methods

To obtain a comparison of growth amongst *A. saccharum* in differing environments, two test sites were chosen to represent an on-campus site with greater human impacts that were defined above, and an off-campus site with significantly lesser human interactions.

The parameters for the on-campus site were defined as the area extending from Lakeside Lab to A Street, and from 20 feet off the shoreline up to the farthest boundary of Upper Drive (Fig. 1A). The second test site was selected for its distance from central campus and its minimal human presence. This off-campus site was located on Grapevine Point, distanced 20 feet from any paths or shorelines (Fig. 1B). Additionally, to eliminate confounding factors that could alter *A. saccharum* growth, test sites were selected for consistent soil type. A map of Cheboygan County, Michigan identified that both sites consisted of the soil type, Rubicon sand.

In order to analyze the growth of each tree at comparative test sites, tree core samples were taken at breast height from 10 on-campus and 15 off-campus *A. saccharum* trees using an increment borer. The selected trees' DBH ranged from 32 to 38 cm to standardize the sizes of the trees. This range was selected since we found it to be the mean range, and representative of the majority of *A. saccharum* trees. After coring the trees, the samples were "dried, mounted, and sanded to prepare them" for microscopic examination for determining annual ring growth (Atkins, 1998). Each tree's annual growth was determined by averaging the tree ring size over 20 years and then dividing by the DBH of the sample tree in order to account for proportionally larger tree rings due to larger tree size. The growth of *A. saccharum* could then be compared between our two tests sites, and analyzed to determine if the following variables correlated to any differences in growth. Soil moisture, soil density, soil nutrients, biomass of neighboring trees, and sunlight intensity were chosen as factors to reveal any correlation to tree growth in areas with differing human presence.

Effect of Soil Moisture on *A. saccharum* Growth

To test soil moisture between the on and off-campus *A. saccharum* trees, a soil core sampler was used to extract soil 1 meter from each sample tree. The samples were placed in a sealed, labeled plastic container. To prepare the soil samples for nutrient analysis, we used a sieve to remove stones and branches, and a ball mill to grind the samples. After the samples were ground, they were submitted to the UMBS Chemistry Laboratory for soil moisture analysis.

Effect of Soil Density on *A. saccharum* Growth

Soil densities between on- and off-campus trees were studied to see if there was a correlation between soil density and tree growth, and if there was a significant difference between soil densities at the two test sites. First, the soil was measured on an electronic scale in grams. Then, the volume of the soil core sampler was calculated to 70.686 mL. Finally, we divided the mass by the soil corer's volume to obtain the density. By using the soil core sampler's volume we could account for the possibility of any soil loss while transferring samples or other human error.

Effect of Soil Nutrients on *A. saccharum* Growth

Nitrate, ammonium, and phosphate concentrations were studied to see if there was a correlation between soil nutrient levels and tree growth, because they are limiting nutrients to most plants. The original soil core samples from both test sites were ground, dried, and submitted for a soil nutrient analysis by the UMBS Chemistry Laboratory.

Effect of Biomass of Neighboring Trees on *A. saccharum* Growth

The total biomass of neighboring trees between our two test sites were studied to see if there was a correlation between biomass of neighboring trees and average annual tree growth of the target *A. saccharum*. We considered any tree within a two meter radius of the target tree to represent a competing neighbor, because it would account for the majority of close underground root competition. A totaled DBH from the trees within the 2 meter radius was calculated to represent the biomass of competing neighbors.

Effect of Sunlight Intensity on *A. saccharum* Growth

The amount of sunlight trees were receiving in both sites was studied to see if there was a correlation between sunlight intensity and average annual tree growth. A lux meter was used to measure the light intensity received by each tree. The meter was placed 2.7 meters high on the south facing side of each tree sample between the time span of 1:55 to 2:18 pm. The 2.7 meter height was chosen to standardize the lux readings, as it was the average height of the lowest branch on the on-campus site.

Results

The first and most prominent comparison made was that of average annual tree growth for our on-campus and off-campus samples of *A. saccharum.* There was, in fact, a statistically significant difference between the two sites. The off-campus site had a larger mean tree growth (0.00466 mm rings/ DBH) than the on-campus site (0.00321 mm rings/DBH) (p-value = .004; Table 1). Since these results show that there is indeed a difference in tree growth between *A. saccharum* trees at the two sites, the results of our selected variables were further analyzed to reveal any correlations between them and tree growth at each site.

Soil Moisture and *A. saccharum* Growth

The mean soil moisture for off-campus trees was 11.2587% by mass and on-campus trees had a soil moisture level of 2.265% by mass. The t-test revealed a significant difference (p-value < 0.005; Table 1). This comparison of the mean soil moisture revealed that the off-campus test site had greater soil moisture content. The greater soil moisture levels at the off-campus site correlated positively with its average annual tree growth (Fig. 2A). For the on-campus trees, soil moisture displayed a negative correlation with average annual tree growth (Fig. 2B).

Soil Density and *A. saccharum* Growth

On-campus trees had a mean density of 1.0938 g/mL, and off-campus trees had a mean density of 0.92387 g/mL.The differences in soil densities were found to be statistically significant by using a t-test (p-value = .004; Table 1). The mean soil densities between the two test sites was compared to the average annual *A. saccharum* tree growth using a linear regression. There was a positive correlation between soil density and average tree growth at the on-campus site. There was no correlation between soil density and the average tree growth at the off-campus site. (Fig. 3A, 3B).

Soil Nutrients and *A. saccharum* Growth

On-campus nitrate levels were found to be lower than off-campus, with a concentration of 0.3806 µg N/mg, compared to off-campus levels of 4.0874 µg N/mg. Similarly, on-campus ammonium levels were lower (2.797 µg N/mg) while off-campus levels were higher (9.7638 µg

N/mg). A t-test revealed that nitrate and ammonium concentrations between our two test sites were significantly different (ammonium p-value, nitrate $p\text{-value} < 0.005$; Table 1). A comparison of phosphate between the two test sites had no significant difference in soil phosphate content (p-value = .391; Table 1). Phosphate levels were found to be lower (13.9461 μg P/mg) on-campus, while off-campus phosphate levels were higher (17.795 μg P/mg). There was a positive correlation between nitrate concentration and average tree growth for the on-campus site, and a negative correlation for the off-campus site (Fig 4A, 4B). Ammonium concentration in both sites showed a positive correlation with average tree growth, and no correlation was made for phosphate (Fig 5A, 5B).

Total Biomass of Neighboring Trees and *A. saccharum* Growth

We compared our data for total biomass of trees neighboring our target *A. saccharum* for both on-campus and off-campus test sites. For the on-campus trees, the mean total neighboring biomass was 9.00 cm. Off-campus trees had a mean total biomass of 15.67 cm. This difference was significant when using a Mann-Whitney U test (p-value = .017; Table 1). The correlation between total neighboring biomass and average annual tree growth was negative for both on-campus and off-campus sites (Fig 6A, 6B).

Sunlight Intensity and *A. saccharum* Growth

Light intensity levels for on-campus trees had a greater mean light intensity (3,670 lux) compared to off-campus trees having a lower mean light intensity (393 lux). There was a significant difference in the mean light intensity between the on-campus and off-campus test sites ($p\text{-value} < 0.005$; Table 1). There was a positive correlation between light intensity and average annual tree growth on-campus trees and no correlation with off-campus trees (Fig 6A, 6B).

Cumulative Influence of Tested Variables and *A. saccharum* Growth

Since all of our selected variables excluding soil phosphate levels proved important for tree growth, there is the possibility that a combination of all or a few of them compounded and acted together to affect the significant results. To test this we performed a stepwise linear regression and found the level of soil nitrates to be the only significant variable affecting tree growth on-campus (p-value = 0.026; Fig. 8A) and ammonium levels to be the only significant variable affecting off-campus soil (p-value = 0.036; Fig. 8B).

Discussion

The significance of the above results are representative of the small community of UMBS, but can be used as a proxy for similar communities.Our interesting finding from our data was that the average annual tree growth of *A. saccharum* samples on-campus and off-campus was significantly different. Off-campus trees showed a greater average annual growth. Our data supported our hypothesis that human presence at UMBS may negatively affect the average annual growth of *A. saccharum*.

The difference in soil moisture levels between the two sites could have arisen from the close proximity of on-campus *A. saccharum* trees to roads or sidewalks, preventing the underground root systems to reach full expansion necessary to maximize moisture uptake (Berrang et. *al.*, 1985). Conversely, the off-campus trees stand in areas with less compaction. This could allow for more soil aeration, hence increased moisture content (Berrang et. *al.*). We found a positive correlation for greater average annual tree growth and greater soil moisture in the off-campus *A. saccharum* trees, this can not translate to an exact causation. Their relationship can be used as a branching point for further investigation on the effect of soil moisture, as it is a prominent environmental factor contributing to the decline of tree growth (Berrang et. *al.).*

Another variable tested related to soil moisture is soil density since dense soil tends to have less water retention, and therefore less moisture (Bhadoria, 1986). The denser soil on-campus could be caused by more human and vehicular traffic on the soil surrounding the *A. saccharum* trees. Even though we did not see a direct negative impact on average annual tree growth in our results, this traffic compacts soil, which can potentially reduce tree growth and vigor while increasing surface runoff of rainwater (Adams & Froehlich, 1981). Additionally, denser soil could be a result of human-built structures and traffic at UMBS, stunting tree growth.

The nutrient level of soil is essential for tree growth. Nitrogen is the principle limiting element for plant growth, but others, including phosphorous still have a measurable, albeit lesser, effect (DeAngelis et. *al.*, 1989). Thus, we included phosphate as an important nutrient in our testing. The off-campus site had considerably higher levels of all nutrients tested, nitrates, ammonium and phosphates. Phosphates in particular can be easily removed from an area due to soil erosion and nutrient runoff, very plausible circumstances at the on-campus site which showed lower levels (Busman, 2002). Additionally, there are many concrete surfaces and less vegetation off-campus and this could lead to decreased nutrient availability and increased nutrient leaching on-campus (Berrang et. *al.* ; Schactman et. *al*., 1998). These findings indicate that the human impact at UMBS could lower the amount of available nutrients for uptake by *A. saccharum*. Also, the Maintenance Staff at UMBS annually collects leaf litter and debris from around the trees on the main sections of the on-campus site every Spring (Fig. 9). Organic waste is a primary source of nutrients for soil enrichment, particularly ammonium and nitrates (O'Leary et. *al*., 2002) This could explain the lower nitrogenous nutrient levels found at the on-campus site and thus possibly explain the lower tree growth there compared to the off-campus site where trees grow amidst the nutrients of fallen leaf litter and organic matter.

Off-campus had more competing biomass surrounding its trees than did the on-campus site. This is supported by a different study looking at the influence of surrounding competition and shading on the growth of western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*) which found that both had greater decreases in growth due to crowding and competition (Canham et. *al.*, 2004). The total neighboring biomass test indicated that a higher amount of surrounding biomass could negatively affect the growth of trees. Thus the on-campus trees benefited from fewer competing neighbors. Their decreased competition is likely a result of tree removal and selective placement for the construction of campus buildings, roads and sidewalks for students and faculty.

Sunlight intensity was significantly different between the two sites. Most likely as a result of its lower surrounding biomass as discussed above, the on-campus site received considerably more sunlight than the off-campus site. The amount of sunlight positively correlated with tree growth for the on-campus trees. Trees tend to grow vertically faster as light availability decreases and competition for the higher canopy light becomes more critical (Bonser et. *al., 1994*). This higher vertical growth and less lateral growth was apparent in the off-campus site and could be explained by decreased light intensity.

Our research also suffered from sampling limitations worth noting, which if corrected could improve the methodology. For example, there could have been inaccuracy in the measurements of the tree rings, as *A. saccharum* produce very faint bands that are difficult to distinguish. We hoped to minimize the effect of this error by averaging the width of each ring over 20 years for each tree. The measurements of soil density could have been similarly altered by human error, as the soil corer was not a secure container. As we extracted the corer from the ground, soil layered on the top of the corer could have fallen out, changing the true density measurement. When designing the methodology to perceive the effect of biomass of neighboring trees, we allowed a two meter radius from the target *A. saccharum*. Perhaps this distance did not accurately measure underground root competition, unfortunately we were unable to know the extent of each tree's root system. Finally, the measure of light intensity was made at the average height of the lowest branches for on-campus trees, where the lowest-hanging leaves were located. At the off-campus site, the trees were much taller and their leaves were spread high in the canopy. There was no way of getting an accurate reading of light intensity at the height of the lowest branches at this site, which could have been more representative of sunlight strength.

The findings from own study could prove useful to the current assessment of landscape planning at UMBS. Furthermore, our study can direct similarly sized communities in other places in maintaining a healthy habitat for both people and vegetation. A recently proposed landscape architecture master plan at UMBS includes high priority plans for new plantings to increase the natural aesthetic and beauty on-campus (Dennis, Strasser, & Superfisky, 2012). Several areas including the Lakeside Lab's front yard, the Manville cabin frontage, Blissville cabin frontage, and the State St. 'Streetscape' (where the majority of our on-campus tree samples were located) were identified as high potential new planting sites (Dennis, Strasser, & Superfisky, 2012). Our findings can guide the types of vegetation that should be planted at UMBS. In the interest of the health of the trees and plants, our study suggests that the chosen species not only be sun and space tolerant, but prefer that environment. The vegetation should be adapted to low soil moisture and high soil density, and grow well in soils with lower amounts of ammonium and nitrate. The landscape architecture report states that "any vegetative interventions employed at UMBS should respond to the existing natural community and character of the site, through the utilization of appropriate native plant palettes and designs" (Dennis, Strasser, & Superfisky, 2012). This intention is commendable, as non-native species could easily out-compete any *A. saccharum* saplings. As our study revealed, increased competition correlates with decreases in average annual growth rate. As the current *A. saccharum* trees on-campus begin to age and die, it would be wise to replace them with trees better suited to lower levels of soil moisture, ammonium, and nitrates, and high levels of soil density and sunlight intensity. Also, *A. saccharum* trees are expected to experience a significant reduction in their range and abundance in Northern Michigan during this century (Prasad *et. al.,* 2007). Recommendations include Hedge Maples or Bur Oaks, two durable trees suitable for the ample space and minimal competition on the UMBS campus; and tolerable of dry, compact soils (Ohio Department of Natural Resources). Since these two species are currently found in Michigan, they would be appropriate choices. Bur Oaks in particular would be an excellent choice since they are expected to spread northeastward over time and further into Northern Michigan (Prasad *et. al.*, 2007).

Our results also enable us to make several suggestions to help improve tree growth at UMBS. First, we recommend that leaf litter not be removed from areas around trees on-campus. Removing leaf litter prevents their decomposition and subsequent nutrient release into the soil. If this is not possible due to fire hazard, or other safety reasons, we suggest composting leaf litter and applying it around the trees as fertilizer. Second, we advise replacing the impermeable concrete sidewalks around campus with porous, permeable surfaces to allow better water percolation and retention in the soil. Third, support the UMBS architectural master plan's rain garden idea, but expand it to areas around trees to increase the catchment and utilization of stormwater runoff reaching trees on-campus. These suggestions may help increase nutrient and moisture levels in on-campus soil and subsequently benefit tree growth.

In the future, we would study other UMBS tree species to see if other trees are being affected in similar ways as the *A. saccharum*. This would allow us to apply our results to all tree growth on UMBS, rather than only one species. We would also hope to study similar small-scale communities to see if our results are widespread in other areas. If our results are present in these other places, we can build upon and broaden our current findings for a more comprehensive examination of human impact on tree growth in small communities.

Conclusion

Ensuring that our small communities have healthy vegetation is essential to maximize ecosystem services we receive from trees, such as carbon sequestration, increased air and water quality, and reduced stormwater runoff (Sustainable Cities Institute). If we ensure that surrounding vegetation is the healthiest it can be, we will mutually benefit within our shared environment, and maximize the ecosystem services listed above. The people living in villages, UMBS, neighborhoods, or just enjoying parks can all benefit from a conscious awareness of the consequences of their actions, and a legitimate effort to minimize negative effects. Slowing the rate of our habitat destruction and urbanization will be a complex and strenuous venture and therefore it is crucial that we strive to manage the natural elements *within* our already-built environments with the greatest care and attention.

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Appendix

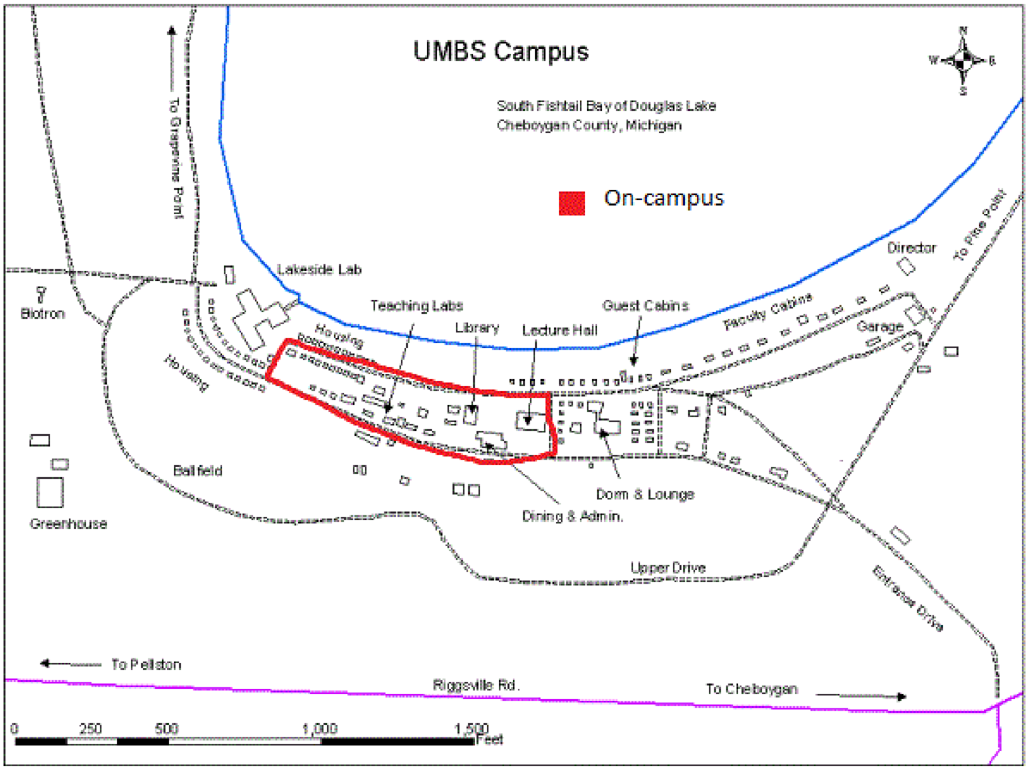

Figure 1A: A map showing our on-campus test site on the University of Michigan Biological Station property.

Figure 1B: A map showing our off-campus test site on the University of Michigan Biological Station property.

Variables	P-Values
Lux	P < 0.005
Neighbor Biomass	P = .017
Soil density	p = .004
Soil moisture	P < 0.005
Ammonium	P < 0.005
Nitrate	P < 0.005
Phosphate	P = .391
Difference between Tree Growth of both sites	P = 0.004

Table 1: Tabular depiction of variables of interest and their respective p-values.

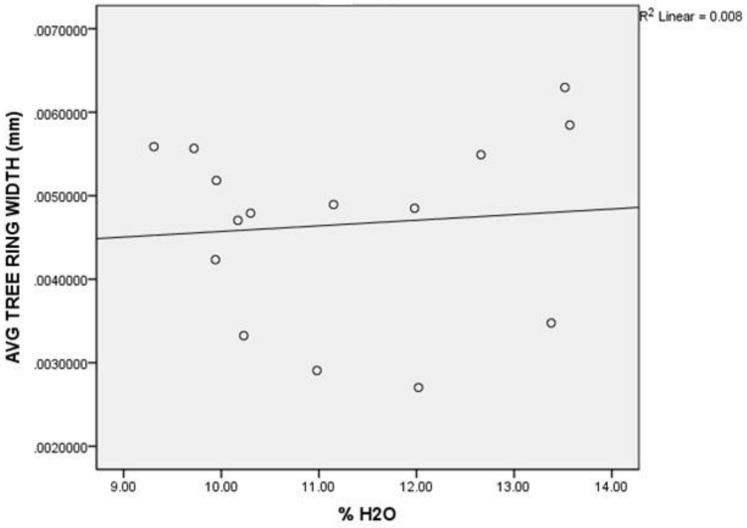

Figure 2A: A linear regression examining the correlation between soil moisture and tree growth off-campus.

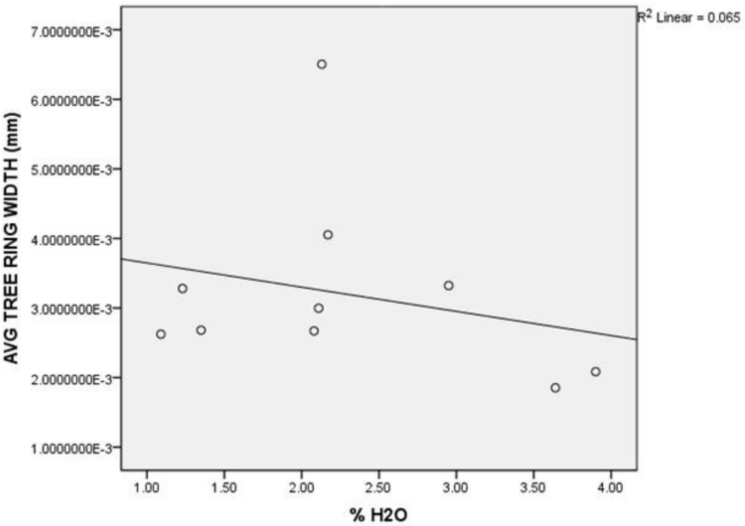

Figure 2B: A linear regression examining the correlation between soil moisture and tree growth on-campus.

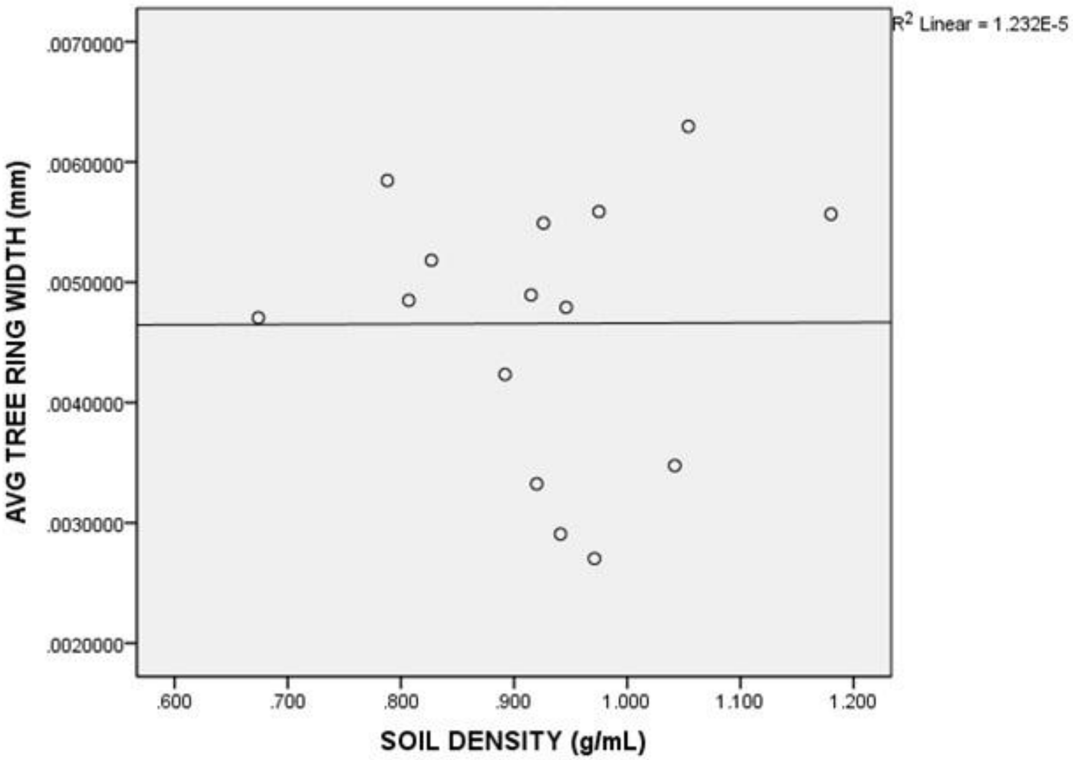

Figure 3A: A linear regression examining the correlation between soil density and tree growth off-campus.

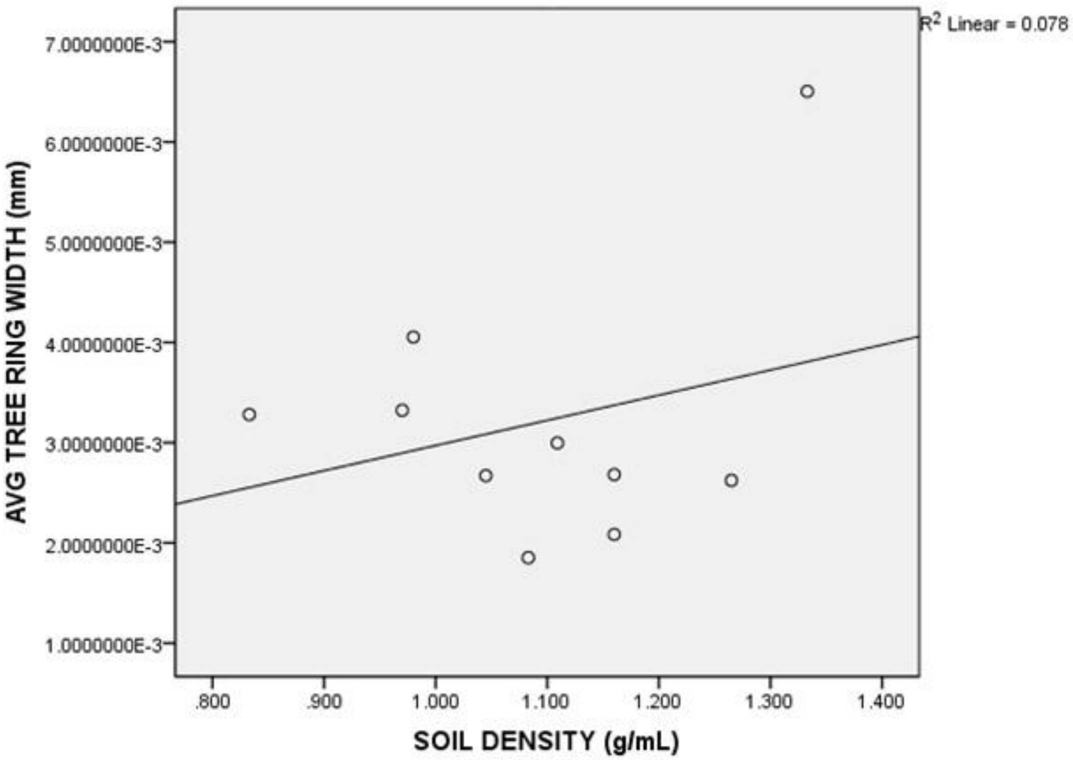

Figure 3B: A linear regression examining the correlation between soil density and tree growth on-campus

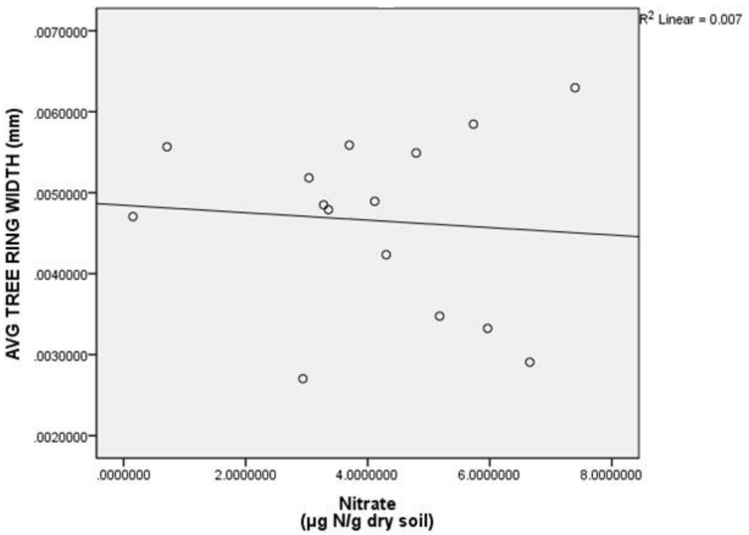

Figure 4A: A linear regression examining the correlation between nitrate concentration and tree growth off-campus.

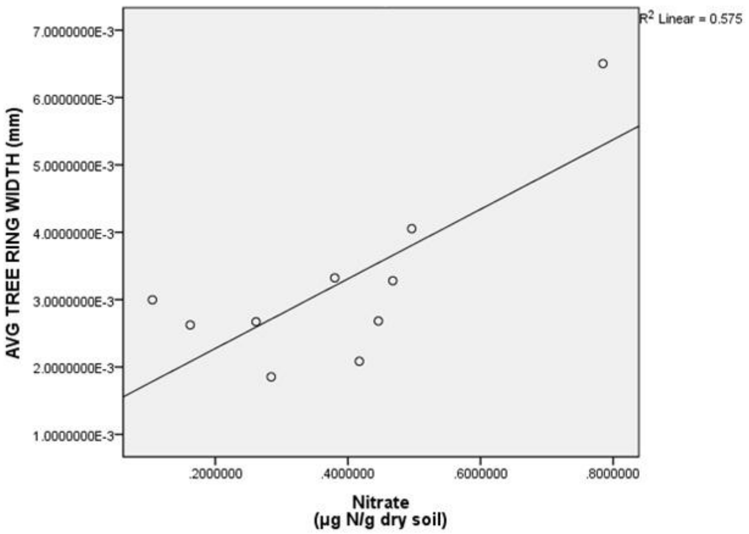

Figure 4B: A linear regression examining the correlation between nitrate concentration and tree growth on-campus.

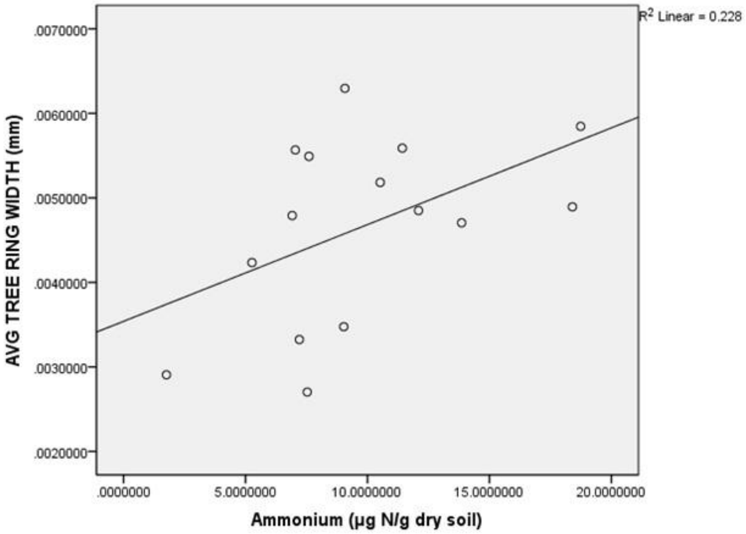

Figure 5A: A linear regression examining the correlation between ammonium concentration and tree growth off-campus.

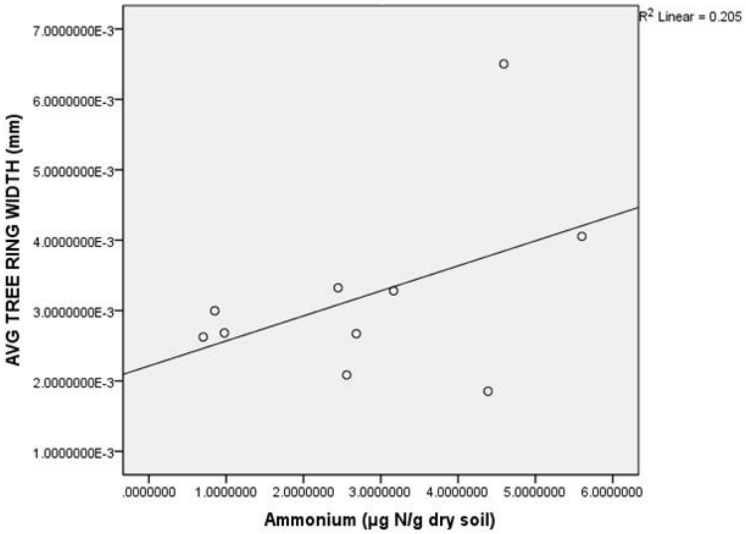

Figure 5B: A linear regression examining the correlation between ammonium concentration and tree growth on-campus.

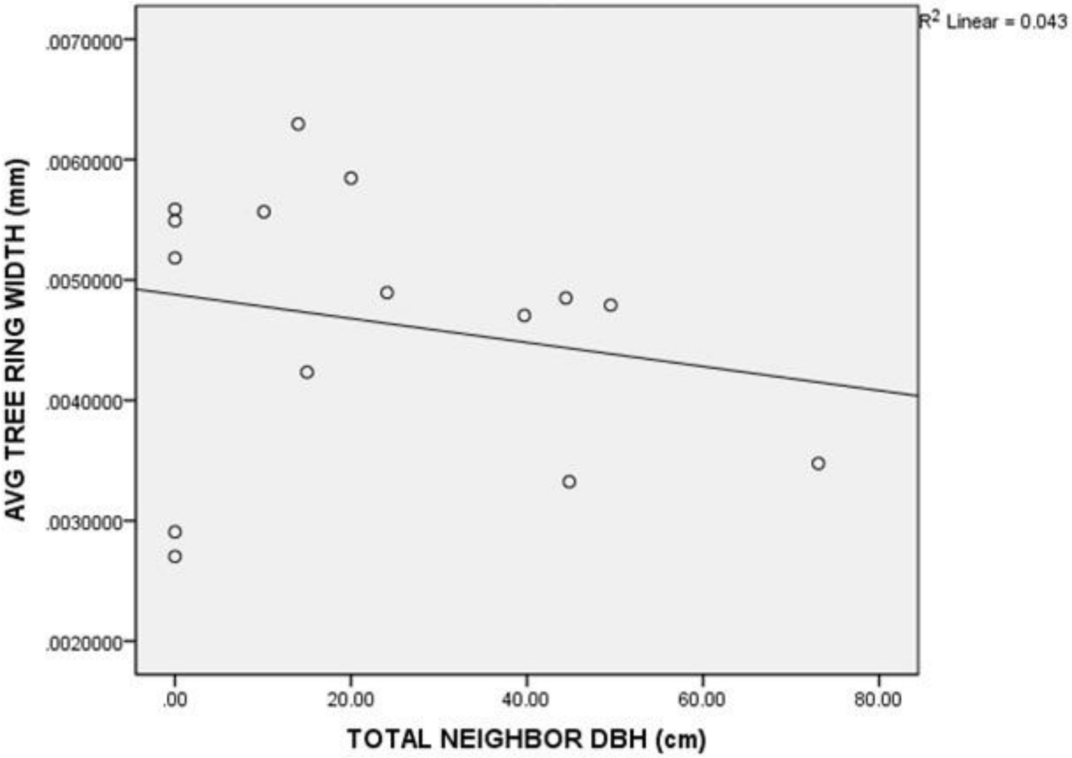

Figure 6A: A linear regression examining the correlation between total biomass of neighboring trees and tree growth off-campus.

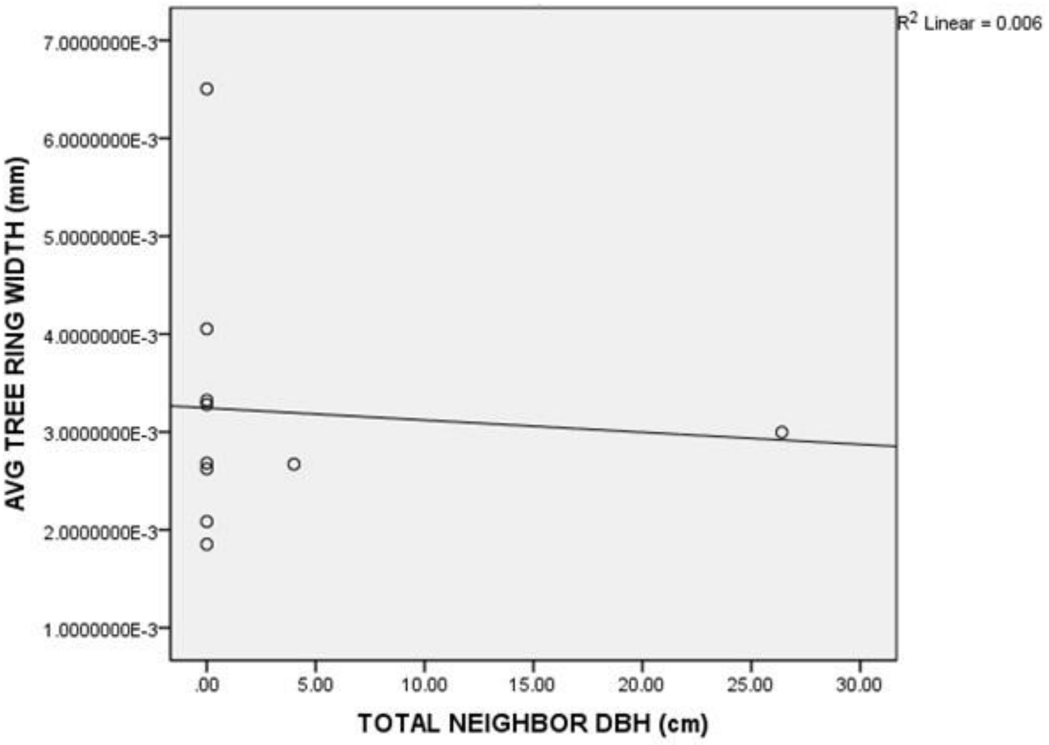

Figure 6B: A linear regression examining the correlation between total biomass of neighboring trees and tree growth on-campus.

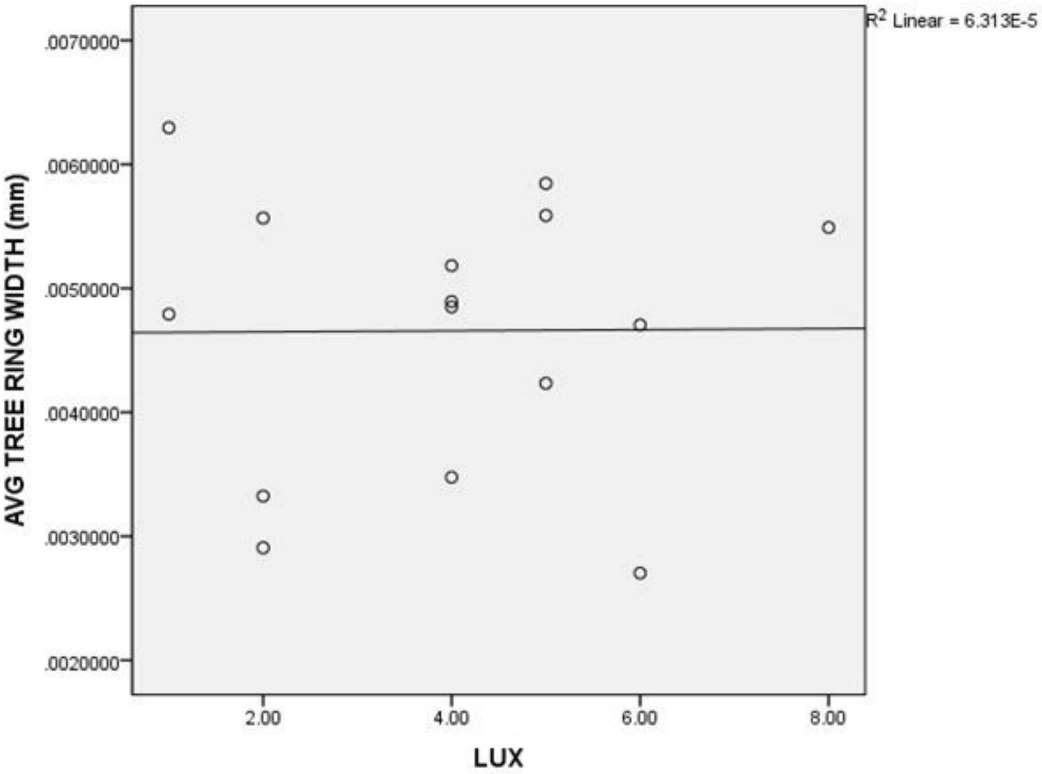

Figure 7A: A linear regression examining the correlation between light intensity and tree growth off-campus.

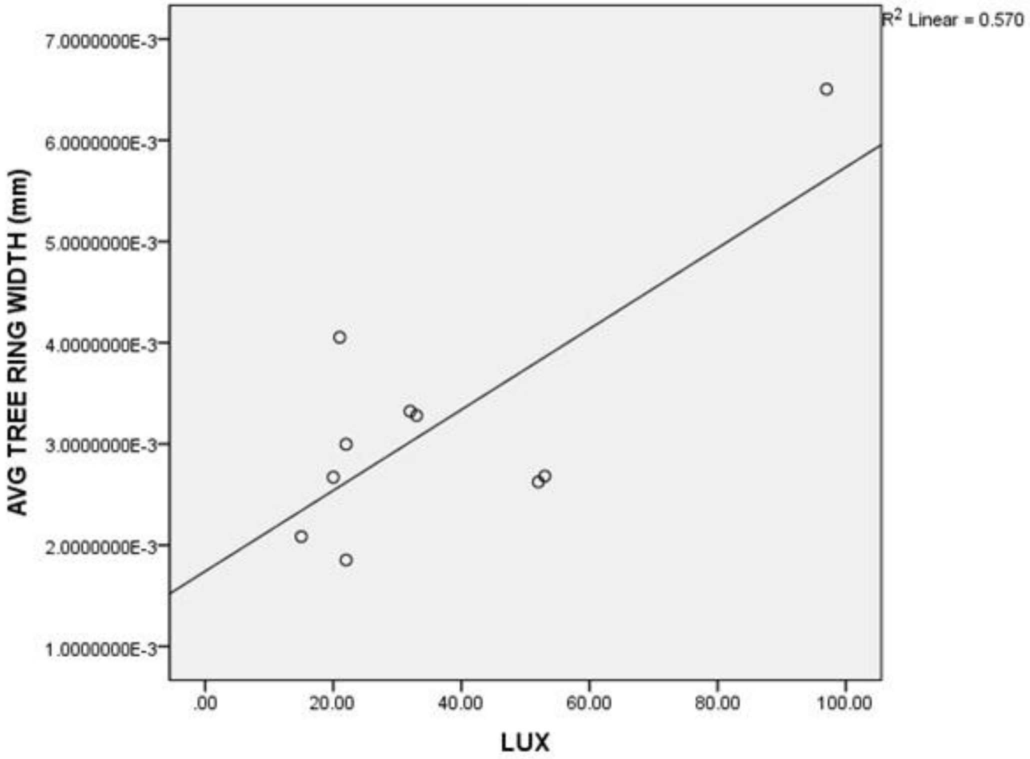

Figure 7B: A linear regression examining the correlation between light intensity and tree growth on-campus.

Coefficients[a,b]

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.

1	(Constant)	.001	.001		1.870	.098
	NITRATE	.005	.002	.758	3.288	.011
2	(Constant)	.000	.001		.528	.614
	NITRATE	.007	.002	1.005	4.284	.004
	TOTALNEIGHBORDBH	7.305E-5	.000	.460	1.962	.091
3	(Constant)	.000	.001		.532	.614
	NITRATE	.005	.002	.727	2.940	.026
	TOTALNEIGHBORDBH	6.536E-5	.000	.412	2.041	.087
	LUX	2.167E-5	.000	.410	1.903	.106

a. campus = 1.00

b. Dependent Variable: AVGTREERINGWIDTHOVERDBH

Figure 8A: Stepwise linear regression for on-campus trees.

Coefficients[a,b]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		

1	(Constant)	.004	.001		5.646	.000
	AMMONIUM	.000	.000	.477	1.959	.072
2	(Constant)	.004	.001		5.855	.000
	AMMONIUM	.000	.000	.524	2.160	.052
	TOTALNEIGHBORDBH	-1.405E-5	.000	-.292	-1.202	.252
3	(Constant)	.004	.001		5.395	.000
	AMMONIUM	.000	.000	.617	2.382	.036
	TOTALNEIGHBORDBH	-1.804E-5	.000	-.375	-1.465	.171
	LUX	.000	.000	-.269	-1.017	.331

a. campus = 2.00

b. Dependent Variable: AVGTREERINGWIDTHOVERDBH

Figure 8B: Stepwise linear regression for off-campus trees.

Figure 9: A picture of a maintenance crew member removing leaf litter on the University of Michigan Biological Station campus.