Carbon Sequestration and the Urban heat Island Effect

Evan Blais

Background Information:

Urban Heat Islands

For a quick run-down of urban heat islands, and the impacts they have here is a great summary video done by The Science Museum of Virginia: https://www.youtube.com/watch?v=s_apVv7dbMQ

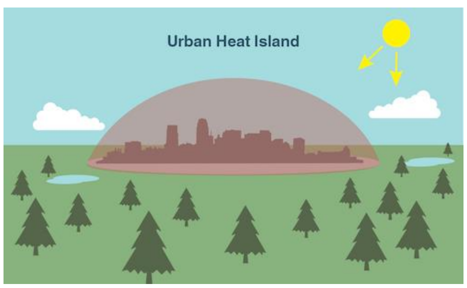


Figure 1: visualization of the urban heta island. Image credit: NASA/JPL-Caltech

An urban heat island is an urban or metropolitan area that is on average far warmer than the surrounding rural areas. The temperature difference between the urban center and the surrounding areas is normally greater during the night compared to the day and is most apparent when winds are weak. As Urban centers grow and the population increases, the area of higher temperatures expand and the average temperatures increase.

The main cause of the urban heat island effect is the conversion of land surfaces from areas with higher albedo to areas of lower albedo. Albedo is the measure of how reflective a material is. Areas with higher relative albedo such as grassy areas or forests absorb less light and radiation in the form of heat compared to areas with lower albedos like buildings or paved surfaces. In a city these low albedo areas absorb heat and increase the temperature of the surrounding areas. Another drawback of these low albedo impervious surfaces, due to lack of vegetation, is the inability of evapotranspiration to occur. This natural process provides much needed evaporative cooling during peak temperatures.

A secondary contributor to the urban heat island effect is waste heat caused by increased energy usage. This waste heat is often the product of air conditioning units being turned on full blast to counteract the increased temperatures, but in reality this is only adding to the problem.

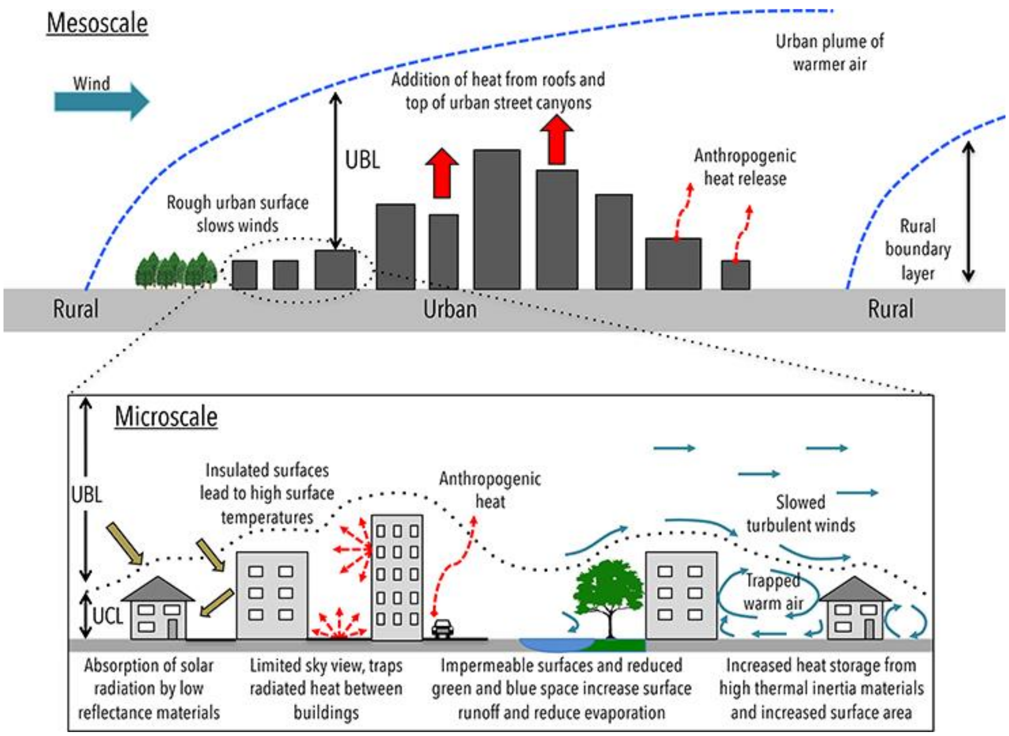


Figure 2: Visualization of the urban heat island on a micro and macro scale. Image Credit: The urban heat island (UHI) by Tristan Kershaw

While humans are the biggest causes of the urban heat island effect, we are also dealing with the greatest consequences. As urban heat islands are largely characterized by increased temperature, they can potentially increase the strength and length of heat waves within these urban areas. These increased temperatures have been reported to also cause heat stroke, heat exhaustion, heat syncope, and heat cramps. Research on urban centers has found that the mortality rate during a heat wave increases exponentially with the maximum temperature.

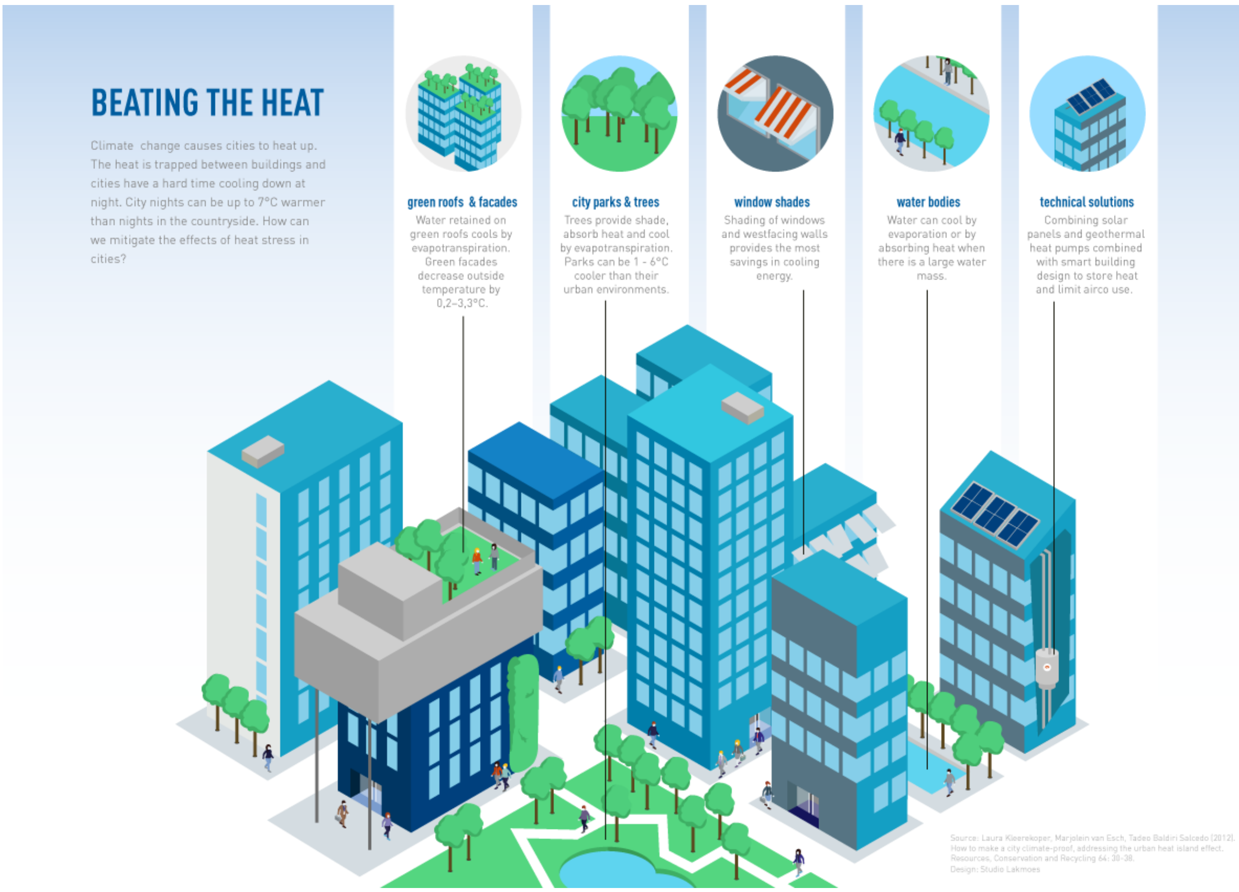


Figure 3: Mitigation efforts in an urban setting. Image credit: Studio Lakmoes

Urban Trees

Urban trees are a vital resource for cities and urban centers due to the fact that they carry out a variety of important processes that are beneficial for the economy, environment, and human health. Higher numbers of urban trees are linked to higher property values, better test scores in schools, and lower crime rates. Spending time near trees can also promote better physical and mental health in all humans.

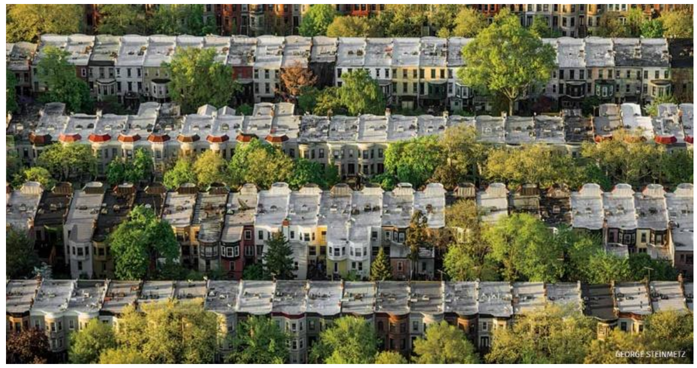


Figure 4: Urban Trees in Brooklyn NY. Image Credit: The National Wildlife Federation

In regard to the environment, Trees also provide habitat for a variety of organisms which promotes urban biodiversity. Trees are responsible for a multitude of ecosystem services including air and water filtration, filtering of pollutants, and sequestering hundreds of kilograms of carbon from the atmosphere.

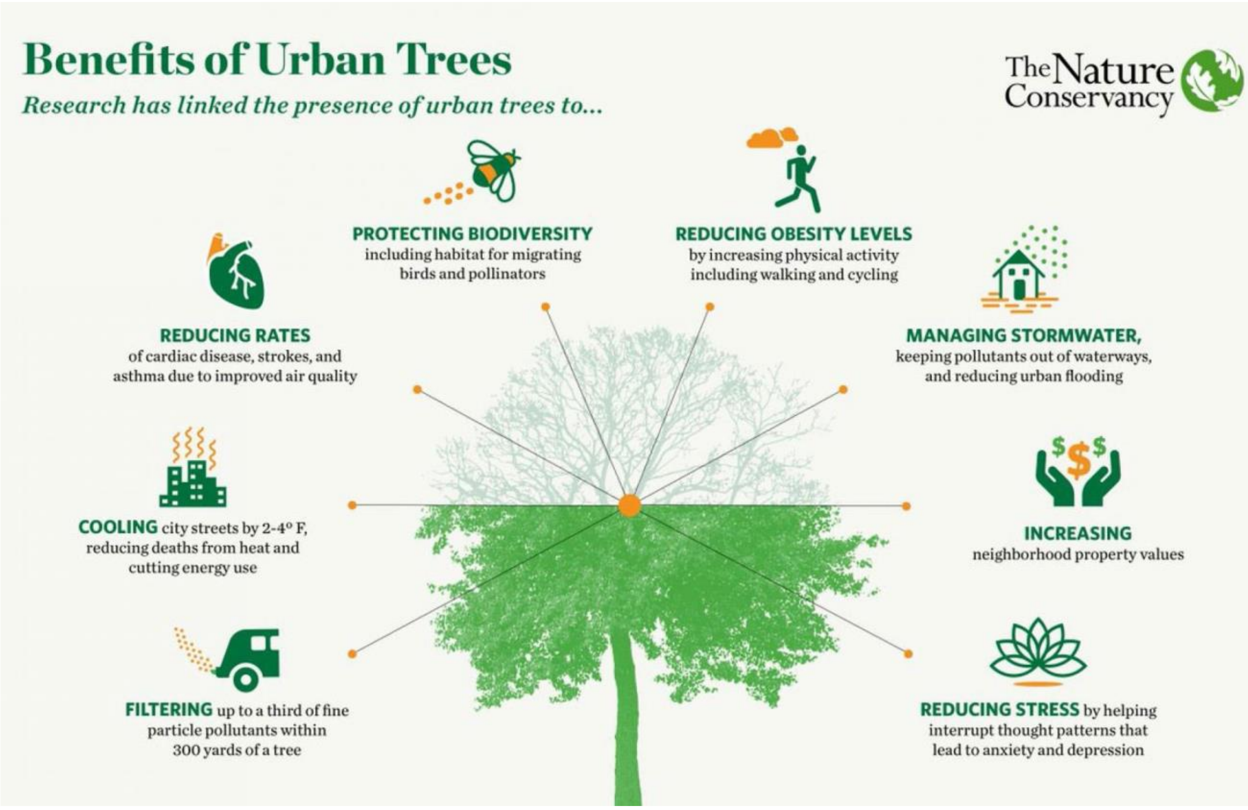


Figure 5: The benefits of urban trees. Image credit: The Nature Conservancy

Carbon Sequestration

Carbon sequestration is the process by which trees and other plants are able to absorb atmospheric carbon, mostly in the form of carbon dioxide, for long term storage and use in biological processes. Trees use this sequestered carbon to produce biomass and grow through the process of photosynthesis. Sequestration is vital tool for human health and for our atmosphere because in one year, an acre of forest can absorb twice the carbon dioxide produced by the average car's yearly mileage.

Urban Heat Island Effects on Carbon Sequestration

The urban heat island effect is largely characterized by increased temperatures within urban centers. These increased temperatures have negative impacts on light-saturated photosynthesis, a necessary process for tree to complete to survive and build biomass. As the urban heat islands grow and temperatures rise the urban trees located on the islands are expected to undergo less and less photosynthesis, thus reducing biomass creation and carbon sequestration.

Without the help of trees, thousands of kilograms of carbon dioxide will be left not sequestered, where it will contribute to the green house effect and speed up the process of climate change. Due to the fact that the trees will grow less and less each year, the situation has the potential to turn into a nightmarish positive feedback loop where urban heat islands grow and the urban trees shrink comparatively.

Linear Regression and Why we use it

linear regression is an easy to use yet very powerful statistical tool that is a type of predictive analysis. The overall idea of linear regression is to determine if a predictor (independent) variable does a good job in predicting an outcome (dependent) variable using a y=a+bx equation. A linear regression operates by creating a model and line of best fit, the model creates a line that ensures the least amount of error between the real data and the model line. If this model outputs a significant P-Value ($p < 0.05$) and a high R2 value, then the model can be used to evaluate trends and predict unknown data values.

Scientist and Research Introduction:

Scientist Introduction

Figure 6: Dr. Emily Meineke. Image Credit emilykmeineke.com

Dr. Emily Meineke is an Urban Landscape Entomologist and assistant professor at the University of California Davis. Before landing in California, Dr. Meineke was a Postdoctoral Associate at Harvard University Herbaria and Duke University, and received her Ph. D in Entomology from North Carolina State University.

Being an entomologist, Dr. Meineke is primarily interested in insect responses to global change and biodiversity protection within developed habitats. Her research on the carbon storage of urban trees has served as the basis for this lesson.

Data Introduction

Raleigh is the capital of the state of North Carolina. Raleigh is known as the "City of Oaks" for its many oak trees, which line the streets in the heart of the city. The city covers a land area of 147.6 square miles and is one of the fastest growing cities in the US. Like most cities Raleigh experiences all of the consequences associated with being an urban heat island.

Raleigh along with most of the southern US is home to *Quercus phellos*, or the Willow Oak, it is one of the largest, most commonly planted shade tree species in the eastern US.

From 2013-2015, Dr Meineke and associates led a study in which the goal was to investigate the above ground carbon storage capabilities of mature urban street trees when in the presence of higher temperatures and common insect pests.

We will be taking the data from this study, and the paper associated with it called *Urban Warming Reduces Aboveground Carbon Storage.* The paper and data can be downloaded for free from https://datadryad.org/stash/dataset/doi:10.5061/dryad.4j43c.

This study investigated a variety of variables but in this lesson we will be focusing on photosynthesis and tree growth as a proxy for carbon sequestration and how they relate to rising urban temperatures.

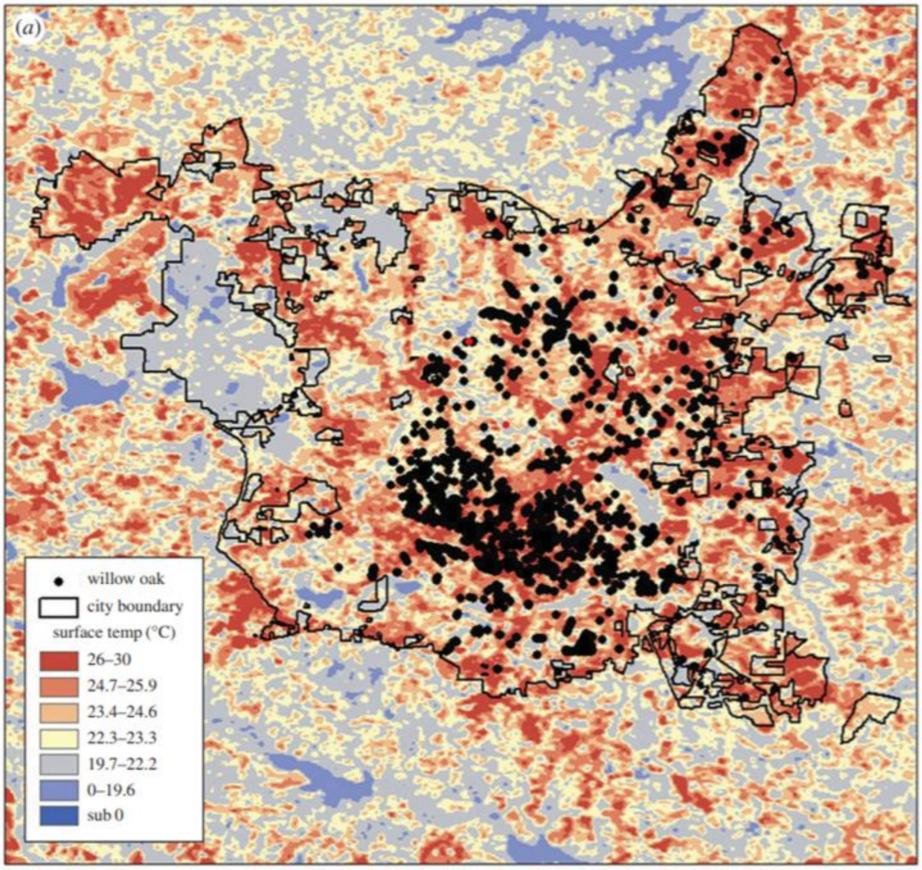


Figure 7: Heat map of Raleigh NC. Image Credit: Meineke E, Youngsteadt E,

Scientific Question

Keeping in mind what we have learned about the urban heat island effect and carbon sequestration, how will the urban trees react to higher temperatures?

Hypothesis

As average temperatures increase, photosynthesis and tree growth (carbon sequestration) will decrease.

<u>Data Findings:</u>

Your Role

As a researcher, you have configured the data inside the open-source data analysis platform called RStudio. Below are several figures and regressions you must now analyze as a scientist. Study them carefully, see what conclusions can be made, and answer the guided learning questions under each figure.

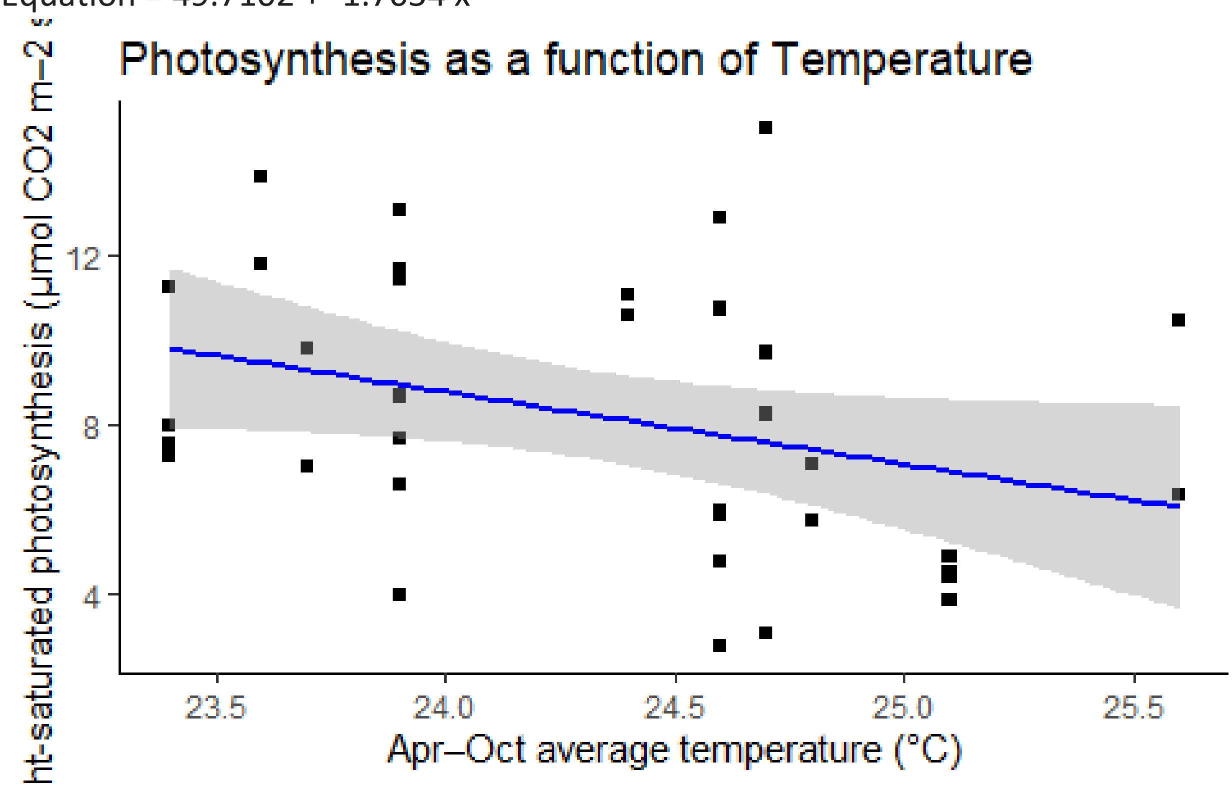
Graph 1: Apr–Oct average temperature (°C) v. light-saturated photosynthesis (μmol CO_2 m^{-2} s^{-1})

Graph 1 is a linear regression specifically examining the average temperature in Celsius during the growing season vs. light-saturated photosynthesis (μmol CO_2 m^{-2} s^{-1})

R^2 = 0.08359

P Value = 0.04839

Equation = 49.7102 + -1.7054 x



1. What conclusions can you draw from this figure? Was this relationship significant? Why? Be sure to include the P-value and R2 values in your answer.

2. There are some high values of photosynthesis associated with high temperature values, what are some possible reasons for these outliers.

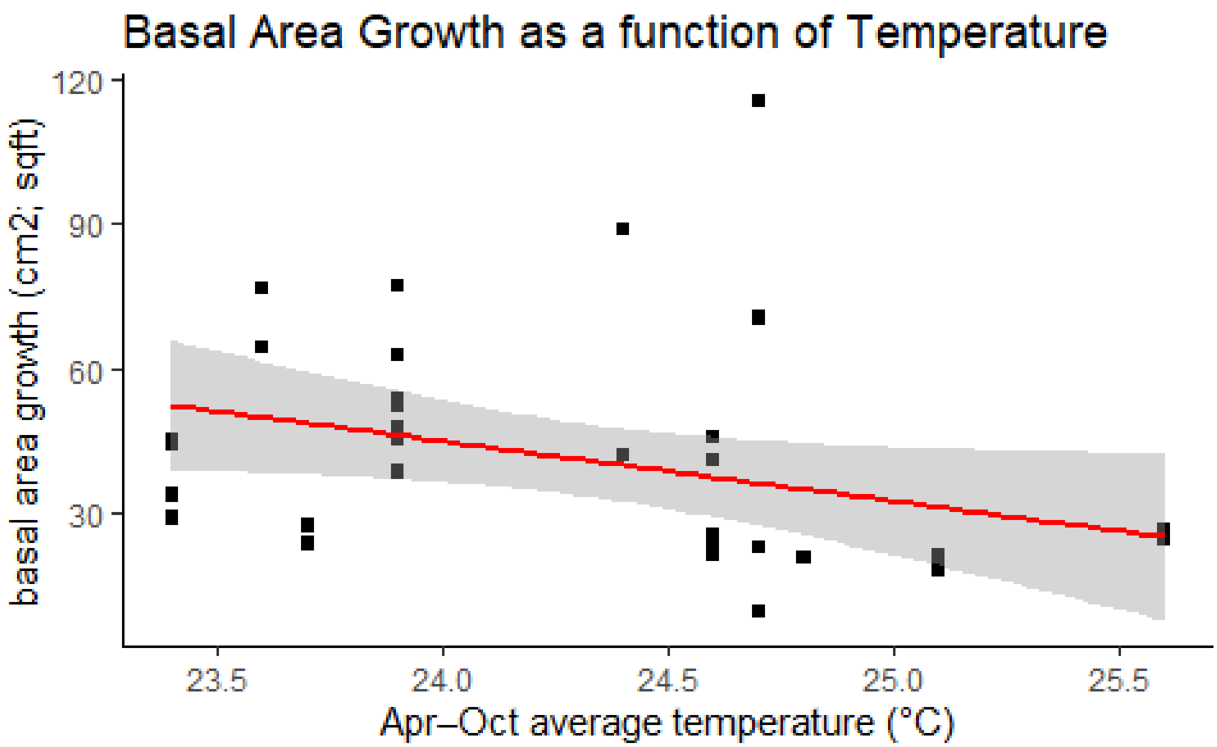
Graph 2: Apr–Oct average temperature (°C) v. Basal area growth (cm2; sqft)

Graph 2 is a linear regression specifically examining the average temperature in Celsius during the growing season vs. basal area growth (cm2; sqft) at 1.4 meters above ground level

$R2 = 0.08604$

P Value = 0.04587

Equation = 342.581+ - 12.395x



1. What conclusions can you draw from this figure? Was this relationship significant? Why? Be sure to include the P-value and R2 values in your answer.
2. There are some high values of basal area growth associated with high temperature values, what are some possible reasons for these outliers.

Final Questions:

1. What were the overall findings of the study?
2. Was the hypothesis supported by the data? Include evidence from the figures to explain why or why not.
3. If we use Photosynthesis and basal area growth as a proxy for carbon sequestration, what can we assume about the levels of carbon sequestration going forward?
4. What are some possible solutions we can implement to help mitigate the effects of the urban heat island on these trees?
5. What are your next steps? Science is an ongoing process and can always be furthered. What new question do you think should be investigated? What future data should be collected to answer your question?

<u>Sources</u>

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