PORTFOLIO COPY - SCIENTIFIC PAPER

IMPORTANT NOTES:

My responsibility for this group project was to write the entire introduction and parts of the Results. My contributions to the results are in bold.

Soil moisture related to canopy cover and informed by socioeconomic factors as a metric for flood protection in Tacoma parks

03/08/2023, 03/17/2023

ABSTRACT

Intensity and occurrence of floods has been increasing in recent years, a trend which is expected to continue. It is important that management strategies to combat these flood events are equitably administered. Parks are one of the main permeable spaces in cities and therefore one of the best ways to estimate general soil water capacity. No studies have been performed on the relationship between canopy cover, soil moisture, and flood mitigation in Tacoma green spaces. The aim of this work was to assess natural flood management capabilities in local Tacoma parks via canopy cover and determine whether socioeconomic factors are impacting these protections. Seven Tacoma area parks were studied for our purposes, with data collected on soil moisture, canopy cover, and tree type. These data were compared to HOLC grades, average annual median income for each census block group the parks were included in, and park age. Analysis indicates a moderate relationship between canopy cover and soil moisture and a strong relationship between age, income, canopy cover, and soil moisture; however, further research is necessary to make reliable conclusions.

INTRODUCTION

Flooding is a growing concern worldwide. The consequences of disastrous floods are extensive, leading to high death rates and destruction of infrastructure (Dadson et al. 2017). Flooding in urban areas may result from flash-flooding, which saturates the ground and reduces the permeability of the soil. To combat this, flood risk management measures include promoting proper forestry practices, such as using trees to intercept precipitation before the entirety of the rainwater can saturate the soil (Zevenbergen et al. 2010). The importance of developing effective forestry techniques to mitigate flooding increases as climate change continues to intensify (Dadson et al. 2017). Scholars are expecting floods to worsen in the upcoming years due to continuous increases in precipitation frequency and intensity (Linscott et al. 2022). Current flood management strategies need to be re-evaluated, however, as present strategies have proved ineffective (Zevenbergen et al. 2010).

One important aspect of preventative flood mitigation is the use of canopy cover. A study detailing the loss of rainfall before it reaches the ground found that leaves on beech trees have water storage capabilities by intercepting and evaporating rainwater (Hörmann et al. 1996). Furthermore, disturbances and reductions in canopy cover have been shown to significantly increase the chance that hazardous flooding will occur (Sebald et al. 2019). Additionally, forest age is directly related to how effective canopy cover is at intercepting rainfall as the tree canopy in mature forests can intercept more water than newer ones (Dadson et al. 2017). Soil properties are also improved in old growth forests (Schrumpf et al. 2011).

Soil permeability plays a large role in moisture retention. In flash-flooding events, soil will soak up a substantial amount of water (Zevenbergen et al. 2010). According to Grillakis et al. (2016) the moisture content of water before a flash-flood event occurs is important. Once soil is completely saturated, it no longer holds moisture and water will run-off, leading to flooding if the magnitude of rainfall is great enough.

Flooding has disproportionate consequences for lower income neighborhoods (Linscott et al. 2022). To better quantify the relationship between income inequality and flooding, it’s important to consider the present-day effects from policies created by the Home Owners’ Loan Corporation (HOLC) in the 1930’s. According to Nardone et al (2021), the HOLC created maps designed to give neighborhoods an “A”, “B”, “C”, or “D” rating according to their perceived risk in receiving loans, with “D” ratings being the least desirable. The maps were based on preexisting segregation making them heavily biased and racist. In the same study, an association was found between poorly rated neighborhoods and less urban green space (Nardone et al. 2021). Additionally, a study focusing on the 2010 Nashville flood found that poorly graded neighborhoods suffer from lack of trees, and that flooding in these areas resulted in not only higher instances of infrastructure damage but greater mortality rates (Linscott et al. 2022). This can be attributed to many factors, but it mainly stems from the absence of preventative flooding measures (Linscott et al. 2022).

In order to properly assess our ideas, we took measurement data from seven different class groups that were assigned to individual Tacoma Metro Parks. Our group's analysis focuses on canopy cover and soil moisture data. Using data collected by all groups, we expect to find that parks with more canopy cover will have lower soil moisture, which is in line with previous findings (Powell and Bork 2007). If canopy cover does indeed have an influence over soil moisture, we infer that increased canopy cover would benefit regions most affected by flooding. Evidence of the effects of forest canopy on natural disasters is scarce, especially in America (Sebald et al. 2019). With this study we hope to add to the body of knowledge pertaining to the relationship between soil moisture, canopy cover, and socioeconomic factors, particularly in urban areas like Tacoma, Washington.

METHODS

Study area

Seven groups from our Environmental Seminar class completed measurements of soil moisture, tree cover, and tree diameter at Frank Alling Park, Garfield Park, Irving Park, McCarver Park, Old Town Park, Puget Park, and Thea's Park. These parks were selected based on similar sizing, main use as a neighborhood park, and varied HOLC grades. Measurements were collected between 4-7 pm on Tuesday or Wednesday and 7- 10 am on Saturday or Sunday during the period of January 26th to February 15th.

Soil moisture

Spaces with minimal cultivation were identified for measurements. We selected three locations that were spaced on opposite sides of the park near non cultivated vegetation. A trowel was used to soften the soil and a Kelway soil tester was inserted at each site. The soil was then packed down around the tester and after a stabilization period of three minutes, the soil moisture was gauged by eye from the bottom scale.

Independent Variables

The independent variables within our study include the age of the parks, canopy cover, tree species, median income, and HOLC grade. The age of the park, along with HOLC grade and median income per block group could influence the species of trees that were planted which determines the canopy coverage of individual species. The canopy coverage of the trees within the park affects the soil moisture level and ability to reduce flooding.

Tree canopy cover

The Canopeo mobile app was used to measure tree canopy cover. We located the five largest trees and verified that they were at least twelve inches in diameter. Using a compass to identify the north side of the tree, we turned to face away from the trees and used the app to take a picture parallel to the ground of the tree canopy. Canopeo then outputs a canopy percent cover.

Species identification

The mobile app iNaturalist was used for tree species identification. Observations were taken of each tree used for measurements of canopy cover and submitted to the class project within the app where project and community members would complete identification. Observations included photos with features individual to each tree such as bark and leaves.

HOLC grading and median income

We used the security map shapefiles available through the Mapping Inequality Project (Nelson et al. 2023) to delineate which areas of our study map were historically “A” “B” “C” and “D” grade. The grade would determine how desirable an area was to live in. We found that two parks were in areas ungraded by the HOLC.

Median income

Both Thea’s and Frank Alling Park were not graded by the HOLC, so we also grouped each park using the median annual income of 2021, as provided by the US census bureau (USCB 2021), for each census block group that the parks were included in. As some parks were in multiple census block groups, the average of their incomes was taken.

Age

Park age was gathered from Metro Parks Tacoma (2023), an independent park district, who shared a table of when parcels were acquired by the park services and additional information such as who is maintaining certain aspects of the parks.

Statistical Analysis

The averages and standard errors were analyzed within Excel. To determine the correlation between the dependent variable of soil moisture, and the independent variables of canopy cover, median income, and park age, we used multiple linear regression and t-tests in the statistical application StatCrunch (c2019). Additionally, we assigned numerical values to our grouped HOLC grading scale to quantify the impact of HOLC grading on the parks used in measurements (A/B = 1, C/D = 2, and no grade = 0).

Validation

To validate our data, pilot sampling of soil moisture, tree cover and tree diameter was conducted on the University of Washington campus by all groups to ensure precision among both equipment and group members. The data collected from the different parks located throughout Tacoma were compared and analyzed, and any possible outliers were removed. During the data collection of Old Town Park, rain was present throughout measurements. To ensure the accuracy of data, we excluded Old Town park's soil moisture data from our analysis.

Possible errors

Reliance on other groups could result in less accuracy, for example data from various groups were completed outside of the required days of week and timeframe. For collection of soil moisture data, the Kelway soil testers scale bars have minimal marks for soil moisture measurement and must be gauged by eye, which may result in subjectivity and a difference in visual perspective depending on the individual completing the measurement. Acknowledging that our study has taken place during winter, it is possible that the measurements of canopy cover could vary during different seasons within the year.

RESULTS

Three soil and five canopy cover measurements were averaged for seven Tacoma area parks (Table 1).

These averages were then compared to the independent variables, like park age. Frank Alling and Garfield, while founded in the same year, have significantly different averages for soil moisture percentage. Thea's Park has the highest percent canopy cover, and Old Town Park is a close second. The oldest park, Puget, has much lower average canopy cover than most of the other parks, but does not have the highest soil moisture.

Table 1: Age of each park with their averaged percent soil moisture and canopy cover.
*Additional acreage was added to Garfield Park through 1927.

Park	Park Age	Average Percent Soil Moisture	Average Percent Canopy Cover
Frank Alling	1912	30.33	8.01
Garfield	1912*	58.33	5.23
Irving	1946	68.00	2.05
McCarver	1960	67.00	0.24
Puget	1888	57.00	0.38
Thea	1996	43.33	15.00
Old Town Park	1940	59.33	13.04

HOLC grade is color- th orange for C and D, green

We found average canopy cover percent for seven Tacoma area parks (Fig. 1). A comparison of Average canopy cover and HOLC grade of the parks shows that Thea's Park has the highest canopy cover, followed by Old Town and Frank Alling. Puget Park and McCarver have the lowest percentage, while Garfield and Irving fall in the middle.

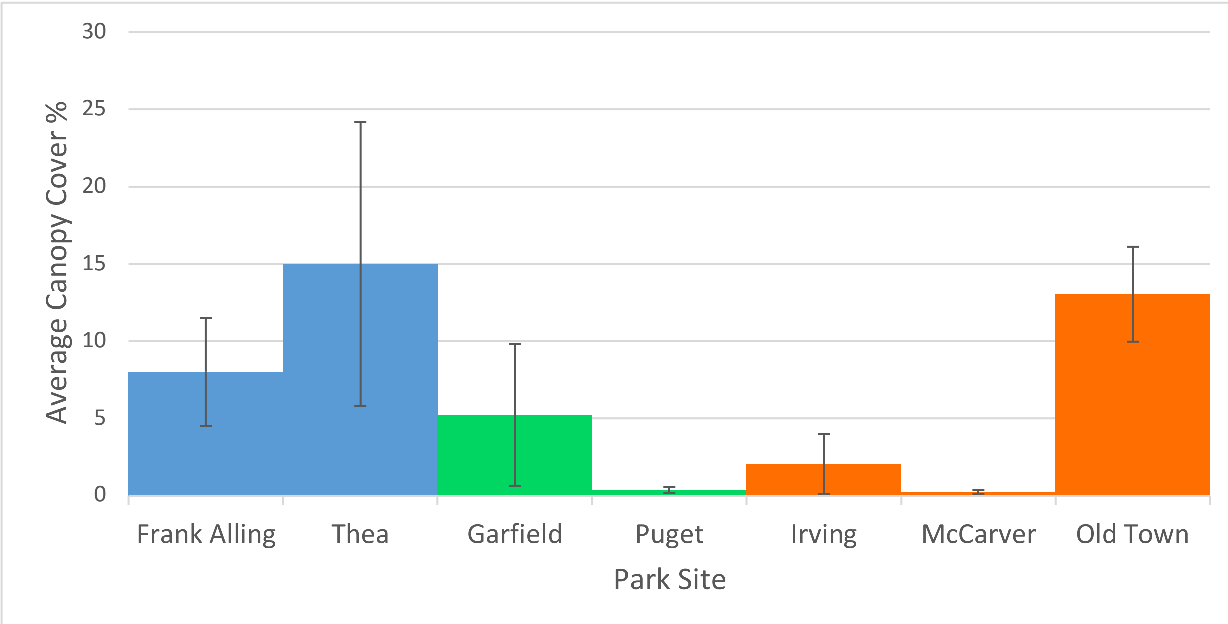

Figure 1. Average percent canopy cover by park site. Standard deviation of the average canopy cover measurements was found for each park. To find percent error, the standard deviation was divided by the square root of the sample size. Percent error is represented by error bars on each park.

Our canopy cover percentages were highly variable (Fig. 2). Only thirteen of the thirty-five canopy measurements were greater than 1% cover, with the greatest being 43%. The three highest of those measurements were for two ponderosa pine trees and a coast redwood tree, both conifers. **Given that the measurements were taken in the winter, it makes sense that evergreen trees had the highest canopy cover percentages.**

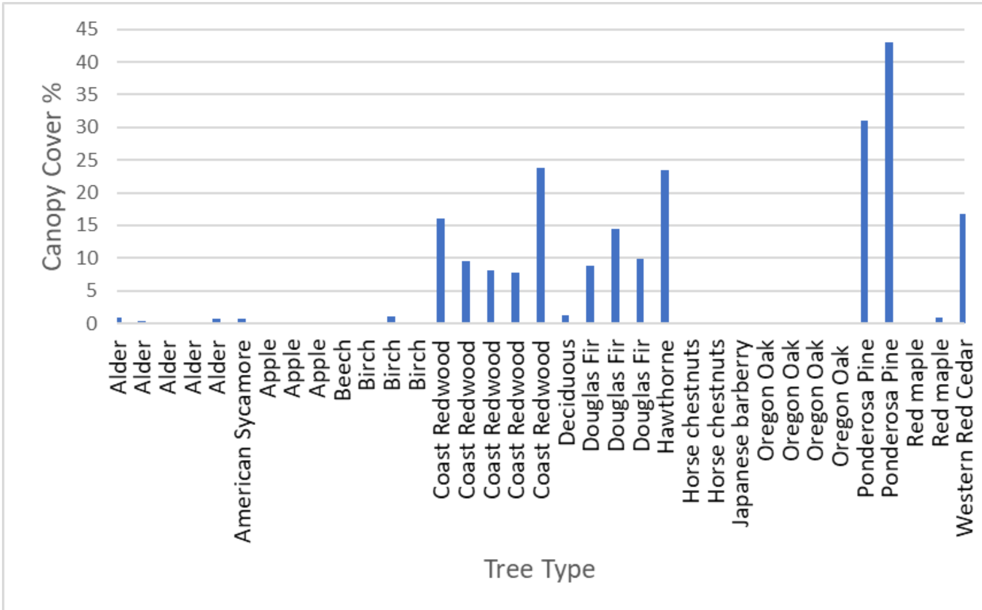

Figure 2. Average measured percent canopy cover by tree type.

Average soil moisture percent was compared to average canopy cover percent (Fig. 3) for six Tacoma area parks. There seems to be a moderate negative linear relationship between canopy cover and soil moisture (R= -0.709, R2 =0.501). Irving and McCarver, both C and D parks, have comparable average soil moisture and are also close in average canopy cover. Due to rain, Old Town Park's soil moisture measurements were considered outliers and omitted from this graph.

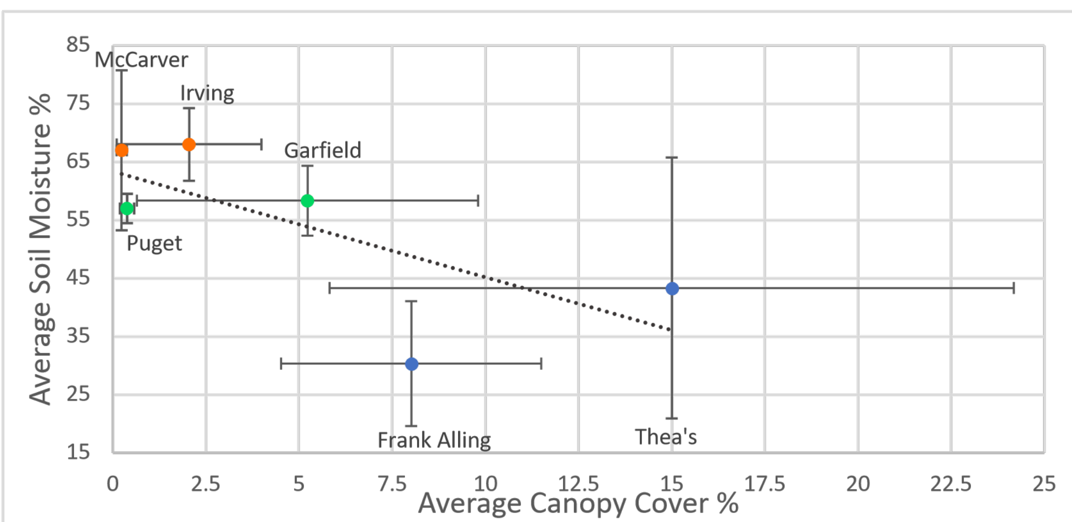

Figure 3. Average measured percent soil moisture related to average measured percent canopy cover for six Tacoma parks. Park names are above error bars for the three uppermost data points and below for the three lowermost data points. Error bars were calculated in the horizontal and vertical direction for both average soil moisture and average canopy cover using standard error of each data set.

Comparing the 2021 median incomes from the seven Tacoma area parks shows that Old Town Park has the highest average median income, followed by Garfield and then Puget. The lowest average median income block was Frank Alling.

Table 2: Median income in 2021 of relevant census blocks for each park and their averages.

Park	Census Block	Median Income ($/year)	Average Median Income ($/year)
Frank Alling	631-3	64,347.00	64,347.00
Garfield	606-1	138,936.00	138,936.00
Irving	617-3	82,042.00	82,042.00
McCarver	617-1	65,799.00	65,799.00
Puget	605-2	144,286.00	123,601.50
	604-2	102,917.00	
Thea	606-1	138,936.00	83,916.33
	602-1	86,563.00	
	616-2	26,250.00	
Old Town Park	605-1	154,798.00	154,798.00

Variations between median income and average canopy cover seem to follow a positive linear pattern within each HOLC grade. We can see that Puget Park, shown below in green to indicate A/B grading, has the second to lowest canopy coverage, whereas Garfield which is also A/B but has higher income has greater canopy coverage. There does not seem to be a strong relationship between average canopy cover and average annual median income (Fig 4; R= 0.2057, R^2= 0.0423).

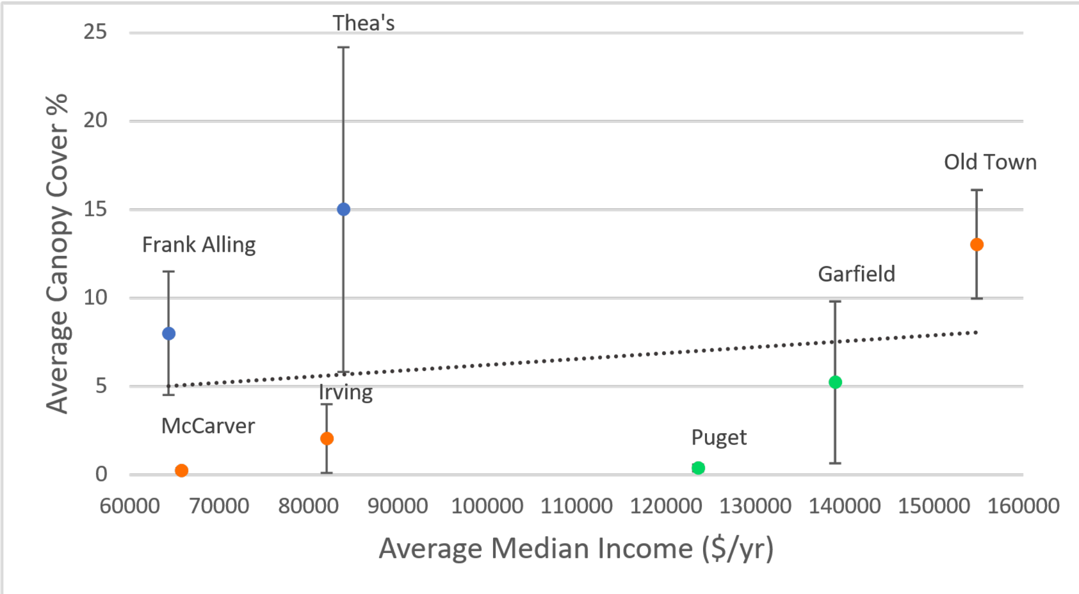

Figure 4. Average measured canopy cover by average annual median income per census block group. Error bars were calculated using percent error from the standard deviation of average canopy cover. Park names are listed above their corresponding error bars.

Isolating canopy cover and income for C and D graded parks displays a strong linear correlation between the variables (Fig. 5; R^2=0.998).

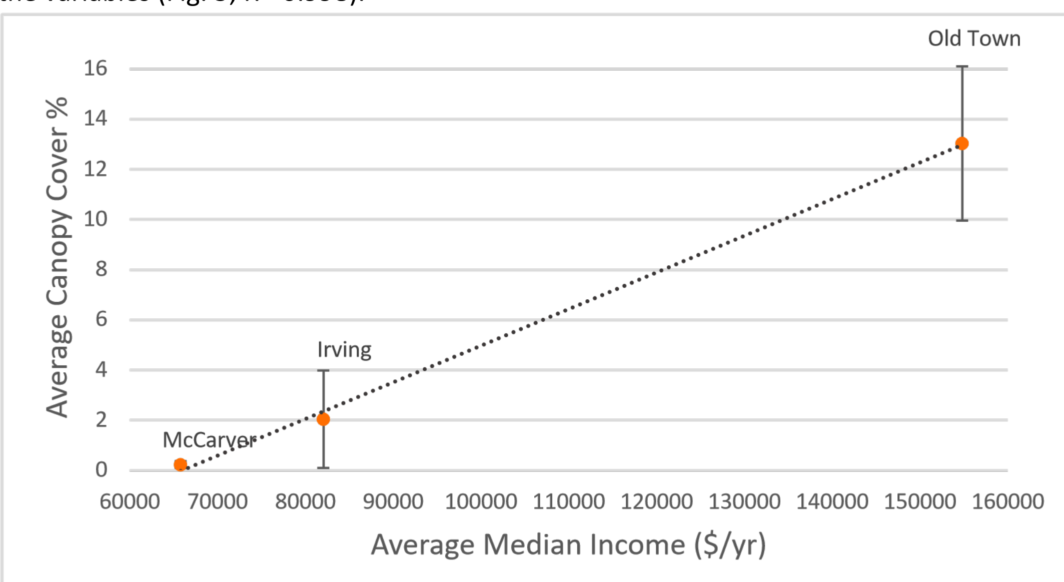

Figure 5. Average measured canopy cover for C and D grade parks by average median income per census block group. Error bars were calculated for each average canopy cover using standard error. Park names are listed above their corresponding error bars.

Table 3. Multiple linear regression for the effects of average canopy cover, average median income, and park age on average soil moisture. Model: Average Soil Moisture ~ Average Canopy Cover + Average Median Income + Park Age (6 Observations). Residual standard deviation: 2.495 (df = 3). R^2: 0.971; adjusted R^2: 0.927. F(3): 22.183; pvalue: 0.043. Signif. codes: '***' 0.001, '**' 0.01, '*' 0.05, '.' 0.1.

Parameter	Coefficient	SE	t(2)	p-value
Intercept	-627.591	123.110	-5.098	0.036*
Average Canopy Cover	-2.874	0.373	-7.713	0.016**
Average Median Income	0.000	0.000	3.833	0.061.
Year	0.347	0.062	5.570	0.030*

Table 4. Multiple linear regression for the effects of average canopy cover, average median income, and HOLC grade on average soil moisture. Model: Average Soil Moisture ~ Average Canopy Cover + Average Median Income + HOLC Grade (6 Observations). Residual standard deviation: 2.264 (df = 2). R^2: 0.976; adjusted R^2: 0.940. F(3): 27.077; p-value: 0.036. Signif. codes: '***' 0.001, '**' 0.01, '*' 0.05, '.' 0.1.

Parameter	Coefficient	SE	t(2)	p-value
Intercept	16.769	8.569	1.957	0.190
Average Canopy Cover	0.829	0.508	0.244	0.244
Average Median Income	0.000	0.000	0.118	0.118
HOLC	19.641	3.182	0.025	0.025*

DISCUSSION

The purpose of our research is to better understand the relationship between socioeconomic factors and flood protection in Tacoma Parks. We hypothesized that due to heavily prejudiced housing practices in the 1930s and 40s by the HOLC, which have been shown to have modern day effects (Nardone et al. 2021), parks that fell in areas with historically favorable grades would be better maintained and therefore have greater tree canopy cover. We believed these differences in canopy cover would lead to inverse differences in soil moisture, as was seen by Storck in their 2000 study. This was important to us because this relationship between canopy cover and soil moisture is an essential element of natural flood protection, as was highlighted in reviews of UK land management by both Cooper et al. (2021) and Dadson et al. (2017). Flood events are expected to increase in the coming decades and have been shown to disproportionately affect communities with a history of C/D HOLC grades (Linscott et al. 2022). Through investigation of the relationship between these variables, we hope to learn how equitable natural flood protection is in Tacoma Parks.

Multiple variate analysis

Multiple linear regression was performed to better understand the relationship between the many variables involved in our study. Changes in soil moisture could be very strongly accounted for (R^2 =0.927) when the relationship between canopy cover, soil moisture, age, and median income was analyzed (Table 3). All but median income demonstrated significant correlation (α =0.05); however, as the number of observations per parameter was small, further investigation is necessary to draw conclusions.

Changes in soil moisture could also be very strongly accounted for (R^2 =0.940) when the relationship between canopy cover, soil moisture, HOLC grade, and median income was analyzed (Table 4). The positive relationship between canopy cover and soil moisture from this analysis indicates the model may not be accurate for all variables involved, however, there still does seem to be some relationship between just HOLC grade and soil moisture, that warrants further investigation.

Park age

Park age (Table 1) was considered for two main reasons: to understand how recently the trees were planted and which groups were invested in the parks when they were built. The groups invested in the parks matter for a variety of reasons. We believe that if the parks were built when the neighborhoods around them had particularly wealthy or influential residents or businesses, then those parties would be more likely to have the resources to contribute to a park with larger, healthier trees (Kaw et al. 2020) as well as ease of access to these parks. When trees were planted matters because canopy cover increases as trees grow and old growth trees have a different impact on soil moisture than younger trees (Schrumpf et al. 2011), a possible explanation for the decreased soil moisture seen in older parks, even when there has been a decrease in canopy cover.

Tree type

Type of tree strongly influences canopy cover, particularly in the winter months when many trees have shed their leaves. The greatest canopy cover seemed to be from trees identified as evergreens (Fig. 2); however, tree identifications were often unreliable or too general to be useful with such identifications as “dicot,” which categorizes most trees, and “plant,” which categorizes all trees. As a result of this lack of reliability, tree type was not a variable we could reasonably include in our analysis.

Categorizing parks by HOLC grade and median income

Two of the seven Tacoma parks were not graded by the HOLC (Nelson 2023). To ensure that socioeconomic factors could be addressed for all parks, we added the category of median income related to relevant Census block groups (USCB 2021). This was also not straightforward, as two of the parks were in multiple Census block groups. Ultimately, we averaged the median income for each block group that the parks were included in (Table 2).

For parks within the individual HOLC groups and the non-HOLC group, there is a positive linear relationship between average median income and average canopy cover (Fig 4., Fig. 5). Our non-HOLC graded parks demonstrate the greatest canopy cover at their income levels and greater canopy cover than both of the A/B graded parks, but our highest income C/D graded park has the second highest average canopy cover (Fig. 4). This could indicate that both wealth and HOLC grading are playing significant roles in the composition of modern parks. One possible reason for this could be increased economic stability in areas that did not have segregated policies. Moye and Thomas (2018) found that integrated neighborhoods had greater home appreciation when compared to predominantly white neighborhoods. Additionally, when examining the characteristics of mixed and segregated neighborhoods, Orfield and Luce (2013) found that diverse suburbs demonstrate values associated with environmental sustainability.

We examined the history of the seven parks in greater depth to determine if there may be less obvious patterns of segregation behind the differences seen in the parks. Garfield Park was built in 1912 (Table 1) and expanded through 1927 (Metro Parks Tacoma 2023). Much of this expansion was thanks to the donations of the Tacoma Land and Improvement Company, which has historically created racially restrictive housing covenants (Restricted properties - Tacoma and Pierce County, c2023). What’s more, in 1927, neighborhoods surrounding Garfield Park were developed and sold by the Minnesota Investment Company with stipulations that only “a member of the Caucasian race shall ever be permitted to own, lease, or rent the property described” (Restricted properties - Tacoma and Pierce County, c2023). Garfield Park is our second highest income park, yet the canopy cover is the median of our data (Table 1), which further supports a relationship between segregated policies and decreased park prosperity. Unfortunately, our study did not collect enough data to make significant claims about these relationships.

Canopy cover and soil moisture

We expected a strong, negative linear correlation between canopy cover and soil moisture which was informed by findings from other areas (Cooper et al. 2021; Storck 2000). While there seems to be a negative relationship between canopy cover and soil moisture (Fig. 3; R = -0.708), only half of the change in soil moisture can be attributed to canopy cover (R^2 = 0.501).

There were multiple variables not accounted for when gathering data that could serve as independent variables affecting our outcomes. First, while we attempted to space out our soil measurements and locate areas with minimal cultivation, the topographic characteristics of where soil samples were gathered could not be further standardized. These characteristics, according to Raduła et al. (2018), are fundamental to accurately determine distribution of soil moisture.

Another variable we could not account for was the proximity of each soil moisture sample to the trees being measured. As canopy cover is the variable being used to gauge soil moisture, if, for example, our highest canopy cover measures are on the west end of a park and our soil samples all need to be taken on the east end, then our soil may not be benefiting from the presence of our measured canopy cover.

A last variable that may have significant impact is how recently and intensely our parks experienced rain. In their article, Raduła et al. (2018) highlight the importance of rain and season in validation of data for given research objectives. Our data were gathered in the same season and we removed any soil data gathered during rain, but we cannot be certain of when the last rain was for each sample or its intensity.

Our ability to make estimates about the relationship between soil moisture and canopy cover for all Tacoma Parks is limited by our sample size which was reduced to six parks with five canopy measures and three soil measures taken at each park. When we analyzed the relationship between canopy cover and soil moisture alone, we did not find significant evidence to support a correlation (t-value = -2.004; df = 4; p = 0.116).

Significance and future work

Our data indicate possible relationships between soil moisture, canopy cover, income, and age as well as HOLC grading that require further investigation; however, we are limited by our sample size and therefore do not have enough evidence to draw significant conclusions about the relationships between the variables studied. While we saw a moderate negative correlation between soil moisture and canopy cover, we did not have enough data, nor was our method of measurement standardized enough to make reliable conclusions. As tree canopy cover helps to prevent waterlogged soil and thereby decreases flood risk, elucidating the relationships between socioeconomic factors and canopy cover could be an important step to ensuring equitable flood protection in Tacoma.

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