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Drought Tolerant Landscaping Trends in Claremont, California

A Thesis Presented

by

Serena Myjer

To the Keck Science Department

of

Claremont McKenna, Scripps, and Pitzer Colleges

In Partial Fulfillment of

The Degree of Bachelor of Arts

Senior Thesis in Environmental Analysis

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Table of Contents

Abstract

The environmental impacts of turf grass lawns are particularly important to consider in California, because of its unique Mediterranean climate and ongoing problems with chronic drought. While California is ideal for agriculture, recreation, and year-round living, the occurrence of drought is natural and not uncommon, evident in historical human and paleoclimate records. Drought impacts humans and wildlife including water scarcity, crop failure, water quality, reduced streamflow, and wetland availability. Diverting water from these critical sources for growing turf grass lawns is inappropriate and harmful. This project is the first analysis of landscaping patterns, trends, and changes in Claremont, California using Google Earth imagery. Among the houses surveyed, we found that 46.75% had changes in landscaping and 53.25% did not change landscaping. Using estimates of water savings from literature, we predicted how much water has been saved by landscape conversion in Claremont. For the median area of turf grass removed, 55.07 m^2, we find that a household is saving around 14,581 gallons per year. This research is an important step towards understanding the impact of landscaping on water usage and advocating for turf grass removal in Claremont and other California cities.

Introduction

Green grass lawns have a special place in our society as a status symbol almost ubiquitous with American life. In fact, turf grass covers almost 2% of all land in the continental U.S., making it the most common irrigated crop (Townsend-Small and Czimczik, 2010). Unfortunately, lawns take a large toll on our environment through excessive water and pesticide usage, introduction of invasive species, and native habitat fragmentation (Medina et. al. 2015; Rani, et al., 2021; Hung et al., 2017). More attention from city planners, homeowners, and water suppliers is being placed on landscaping alternatives in order to reduce the water usage and prepare our cities for future and ongoing symptoms of climate change and drought (Medina et. al. 2015).

The environmental impacts of lawns are particularly important to consider in California, because of its unique climate and ongoing problems with chronic drought. While California is ideal for agriculture, recreation, and year-round living, the occurrence of drought is natural and not uncommon. For this reason, native vegetation has adapted effective water saving strategies to survive the dry summers or years (Prugh, et al, 2018). Landscape designs with high water demand, like lawns, require water to be imported from other states or pumped in wells from natural aquifers. California has a Mediterranean climate, meaning dry summer and wet winters, which build snowpack (and the summer's water supply) in the Sierra Nevada mountains. But in drought years this might not be enough water. Drought is a temporary condition with below average precipitation levels leading to reduced water availability, soil moisture, and groundwater (Mishra and Singh, 2010). This differs from aridity, which is a permanent climatic condition where demand is greater than supply from the permanent long term average water supply, such as in California's Mojave desert (Maliva and Missimer, 2012). Drought can have a severe impact for both humans and wildlife including crop failures, increased water scarcity, decreased hydroelectric production, changes in water quality, or reduced streamflow and wetland availability (Mishra and Singh, 2010). Diverting water from these critical sources for growing green lawns is unnecessary and harmful, especially in arid locations.

Paleoclimate reconstructions from tree rings find that multidecadal droughts are a frequent occurrence in Central and Southern California (Griffin and Anchukaitis, 2014). However, recent droughts have been much different from historical drought records, sparking concern. Between 2012 and 2016, California experienced a record drought in which 2012-2014 were the 3 driest years on the observational record between 1895 to 2014 (Mann and Gleick, 2015). That drought period was unprecedented not only due to low precipitation but also record high temperatures from anthropogenic climate change. Analysis of reconstructions found that 2014 is the worst single drought year of the last ∼1200 years in California due to low precipitation combined with record high temperatures (Griffin and Anchukaitis, 2014). High temperatures increase the severity of drought by enhancing evapotranspiration and decrease available soil moisture (Luo et al., 2017). In addition to less precipitation, rising temperatures due to climate change lead to less snowpack in the mountains that melts sooner in the year, as opposed to a slow release over the course of the summer. This water ends up in dams but is less available to the ecosystems and people that rely on the steady river flow (United States Environmental Protection Agency, 2016).

Historical drought records are instrumental in describing the past, but they also give us an idea of what is to come, since climate change is expected to make future years hotter and drier. It is estimated that climate change has already caused a three degree Fahrenheit increase in southern California (United States Environmental Protection Agency, 2016). Modeling of future drought risk in Western North America finds that in moderate and high future emission scenarios (as defined by the International Panel on Climate Change) will exceed the driest centuries of the Medieval Climate Anomaly (1100–1300 CE) and introduce unprecedented drought conditions (Cook, Ault, and Smerdon, 2015). Models from Diffenbaugh, et. al. (2015) find that human activities have already increased the probability that any future dry precipitation years are also warm. Furthermore, climate modeling indicates that rising temperatures can push “moderate” drought conditions into severe droughts by further drying out the soil, conditions that are likely responsible for the exceptional 2000-2018 drought severity (Williams et al., 2020). Yet, climate change is also expected to create an “intensified water cycle” whereby wet years are wetter and dry years are drier due to increased temperatures (Swain, et al., 2018). We have already seen the results. Following the 2012-2016 drought, the 2016-2017 winter was extremely wet, flooding roads and overflowing the Oroville Dam. Increasing precipitation volatility is expected despite only modest changes in mean precipitation, presenting an additional level of uncertainty, and a challenge to planning for water storage (Swain, et al., 2018).

As of 2022, and throughout the collection of data for this report, drought conditions are rapidly changing, producing troubling results. In October 2021, Governor Newsom reinstated (from Gov. Jerry Brown in 2017) the state of drought emergency, requiring water suppliers to implement water shortage contingency plans. This reinstatement was long overdue, as 2022 is the third year of drought in California (NOAA). In fact, new research on soil moisture demonstrates that 2000–2021 was (and will likely continue to be) the driest 22-yr period in the North American Southwest since at least 800, putting California in a megadrought (Williams et al., 2022). January and February of 2022 have been the driest ever recorded in California (Smith, 2022). It was last measured this year that statewide snowpack was at 57% of normal (Smith, 2022). As a consequence, the State Water Project has announced that water allocations to member agencies will be 5% of normal (Smith, 2022). Southern California's biggest supplier of water is the Metropolitan Water District (MWD), which gets 30% of its water from the State Water Project (Smith, 2022). Claremont receives its water from the Golden State Water Company which gets 60% of its water from groundwater and the remaining 40% from the MWD (Golden State Water). With this vast reduction in water, member agencies and water retailers will likely be calling on residents to reduce water. MWD announced in March 2022 that it will spend $10.5 million in advertising for water conservation, including advocating for drought tolerant landscaping (Metropolitan Water District of Southern California, 2022).

Utilities have to increase prices to pump groundwater and treat low quality water during drought times. Drinking water supplies were greatly depleted during the last drought, especially straining wells in rural communities already vulnerable to high costs, contamination, and maintenance issues (Lund, et al., 2018). A drought and equity survey in California found that all water systems experiencing water shortages were in disadvantaged or cumulatively burdened communities, and that low-income households pay between 2 and 5.3% of their income in drought charges (Feinstein et al., 2017). Already in 2021, 975 households mostly in the rural Central Valley reported dried up wells (James, 2022). Since rural communities typically depend on shallow wells, further reductions in groundwater due to pumping for urban use (like landscaping) or agriculture could leave increasingly more communities without water (Lund, et al., 2018).

Reducing water usage and demand is a momentous task especially since the population size of California has grown 80% since 1976-1977, putting water and goods that depend on water, like agriculture, in even higher demand (Mann and Gleick, 2015). Even so, the agricultural industry in California is huge, consuming about 80% of the state's water supply (Luo et al., 2017). In the last drought, the California agriculture industry lost $2.7 billion in 2015 and $603 million in 2016 from crop revenue losses and expensive groundwater pumping (Howitt et al., 2014; Medellín-Azuara, et al., 2016). In 2021, the California agriculture industry lost $1.2 billion, 8,700 jobs, and farmers left 395,000 acres unplanted (Medellín-Azuara, et al., 2021). This leaves the remaining 20% of water to be divided between all of the people, organisms, and industry in California. In the 2012-2016 drought, water shortages to forests killed 102 million forest trees and left the remaining trees drier and more susceptible to disease and insect infestation, and wildfire (Lund, et al., 2018). Chinook salmon are keystone species in California which depend on river flows from the Shasta Dam. They experienced one of the lowest rates of "egg-to-fry" survival in years with state biologists estimating only 2.56% of the winter-run eggs hatched and survived (James, 2022). Without proper management of the Shasta Dam, California could lose the Chinook salmon, and fishermen and indigenous people could lose their access to livelihoods and cultural traditions (Feinstein et al., 2017).

Yet, the California government has yet to instate mandatory water restrictions on households, cities, commercial industry, or agriculture, instead calling for state residents to voluntarily reduce water usage by 15% (James, 2021). This is in comparison to former Governor Brown's mandatory reduction by 25% in 2012-2016 (James, 2021). Unfortunately the state has only cut back 6.5%, and urban water use has increased by 2.6% compared to 2020 (Smith, 2022). Between 2014 and 2017, Los Angeles reached its city-wide goal of reducing water use by 20% (Save the Drop!). This shows that Angelinos can save water when motivated correctly, and must continue to do so as California's conditions continue to worsen with climate change.

One strategy that California and other southwestern states have implemented to reduce outdoor water use is to offer rebates for households who convert their lawns to drought tolerant landscaping (Medina et. al. 2015). Outdoor water use such as landscaping, power washing, or car washing make up a large portion of overall household water usage and are not essential to our survival, making turf replacement an easy target for water conservation. Household outdoor water use represents 54% of the total water use for single-family households in Los Angeles County (Medina et. al. 2015). According to the City of Claremont and Golden State Water (Claremont's water supplier), around 70% of Claremont's water usage goes to landscape irrigation. In cooperation with municipalities and water suppliers, cities in Los Angeles County including Claremont, have offered financial rebates for homeowners who have converted their yard from lawn to drought tolerant landscaping. The rebate program in Los Angeles from Metropolitan Water District began in 2008 at $0.30 per square foot of lawn removed and then $1 in 2011, and $2 in 2014 for a total of around $350 million in rebates (McNary, 2019). In Claremont and many other cities, rebates from the water supplier were augmented by money from the city, further incentivizing households to conserve water. The program was extremely popular, replacing around 100 million square feet of lawn (Kim, 2016). Mean predicted water savings for single-family residential households in California and Nevada are estimated at 24.6 gallons per square foot per year (Tull, Schmitt, and Atwater, 2016). Los Angeles County participants in the rebate program save 1.9 billion gallons of water every year (Save the Drop!). The program was so popular it exhausted its funding in 2015 and Metropolitan Water District did not renew funding in 2016 (Kim, 2016). However, the program returned in 2019 and now Los Angeles County cities and member agencies serviced by MWD can receive $3 per square foot for up to 5000 square feet of lawn converted to drought tolerant landscaping (Los Angeles Department of Water and Power). Since its origination in 2007, the program now has more restrictions including no plastic grass, gravel covered yards, or non-permeable surfaces and the mandatory inclusion of a water retention feature like a bioswale and three inches of mulch to trap soil moisture (McNary, 2019).

Importantly, households that convert to drought tolerant landscaping can have a "multiplier effect" on their neighbors, in which the neighbors are influenced to switch out their turf as well (Matlock, Whipple, Shaw, 2019). Analysis of the rebate program participants in Long Beach found that a block with a single conversion (program participant) is 5.8 times more likely to have other rebate applicants (Torpey, 2017). These results agree with Matlock, Wipple, and Shaw who found that on average 2.5 neighbors out of 13 converted their landscaping from turf to drought tolerant after a neighbor did so (Matlock, Whipple, Shaw, 2019). As well as Pincetl et al, who found that 36% of participants in the rebate program between 2014-2016 had neighbors with low to no lawn cover (Pincetl et al., 2017).

The turf replacement rebate program is also a way to financially encourage households to switch to drought tolerant landscaping. The rebate can significantly decrease the cost of putting in a native plant garden and the initial costs will eventually recoup in water cost savings between

6 to 11 years, depending on the rebate amount (Medina et al, 2015). The average single-family household that participated in the rebate program between 2013-2014 reduced outdoor water usage by 73 percent annually, saving around $627 per year (Medina et. al, 2015). This value is dynamic depending on the cost of water, size of the yard, and rebate price, but economic incentive can be a main motivator for some households. For example, in Las Vegas drought tolerant landscaping saved 76% of outdoor irrigation and 30% of overall water consumption, totaling to savings of $206/year and 55.8 gal/sq ft annually (Sovocool, Morgan, Bennett, 2006). However, one of the major disadvantages of the program is the initial down payment that many homeowners cannot afford or justify when making the switch to drought tolerant landscaping (Medina et al, 2015). Cities with additional rebates and higher levels of homeownership were more likely to use the program (Pincetl et al., 2017). This often leads to clustering of participating households in suburban areas and far less participation in the most urban and central parts of the city (Pincetl et al., 2017).

Apart from the immense water use associated with lawns, there are other environmental consequences associated with their cultivation. Lawns are made up of grasses that are not native species. Typical grass species in the United States are Bentgrass (*Agrostis spp.)* and Kentucky Bluegrass (*Poa paratensis)* which are both native to Europe. As a result, they are more stressed by warm temperatures, water shortage, and poor soil conditions making them susceptible to disease and weed invasion, leading to pesticide use (UCNAR). While not all homeowners use pesticides to maintain their lawns, it is still important to mention since pesticides are known to pose a serious threat to wildlife and human health. They are linked to cancer, diabetes, lung disease, asthma, reproductive fertility disorders, and even neurological disorders (Rani, et. al, 2021). Pesticides have been identified in surface water, groundwater, and topsoils, arriving from leaching from agriculture or lawns, and killing terrestrial and marine organisms through direct ingestion (Rani, et. al, 2021). Concerningly, pesticides also bioaccumulate (increase in concentration between organisms) through food chains leading to weakened eggshells in high level consumers like bald eagles (Rani, et. al, 2021). Although many pesticides are banned or have lost their potency as targeted pests have developed resistance, pesticides are continually being developed, with the United States using about 24% of all pesticides globally (Rani, et. al, 2021). The commonly available pesticide, Roundup, and other glyphosate-based herbicides have toxic effects including causing liver disease and dysfunction in rats exposed to low doses of the chemical (Mesnage, et al., 2017).

Replacing lawn with native plants supports both local biodiversity and water conservation efforts. Lawns are a monoculture of one species that does not support the vast biodiversity present in Southern California and sets the unfortunate precedent of not cultivating native species in their natural habitat (Adams, et. al, 2020). Since lawns make up the same plant species composition, their widespread acceptance and cultivation contributes to the homogenization of urban landscapes and loss of urban biodiversity (Ignatieva, 2011). Native California species include rare and endemic plants and insects that have intrinsic value to the region. In fact, California is recognized as a biodiversity hotspot with 5,500 native plant species and 2,387 endemic plant taxa (Lancaster and Kay, 2013; Loarie et al., 2008). While there are non-native drought tolerant plants that can live and thrive in California, they do not provide the same benefits for biodiversity as native plants. Studies of plant response to drought demonstrated that all plants responded negatively to low water conditions, but invasives showed more negative responses for growth and reproductive traits when compared to native plants (Valliere et al., 2019). Despite this, most drought tolerant landscaping focuses on water conservation and not specifically native plant and biodiversity enhancement.

Closely related to the diversity of plants is that of insects, since many insects feed on plants and require them for habitat (Ballmer, 1995). Most insects evolved alongside native plants and depend on one or a few plant species, which is why planting native gardens is so critical to supporting biodiversity (Warren et al., 2021). However, recent scientific publications reporting long term trends in insect decline have highlighted global decline of terrestrial insects by 9% per decade and extinction threat for over 40% of insect species (Sánchez-Bayo and Wyckhuys, 2019; van Klink et. al., 2020). Specifically, specialist bee species are found in greater abundances in native plant nurseries than ornamental plant nurseries, indicating that plant assemblages are essential in attracting and maintaining native bee populations (Cecala, 2021). Furthermore, native bees are more attracted to diverse wildflower plantings where flowering is sustained over the season (Williams et al., 2015). As far as non-pollinator insects, insect species richness and abundance were >30% higher and insect composition was similar across sites that hosted either native or drought-tolerant plants, regardless of the degree of urbanization (Adams, et. al, 2020). For gall-inducing insects, native plants host more species than non-native plants, typically on woody species like oaks, willows, and goldenrods (Warren et al., 2021). Insects support a wide range of ecosystem services such as pollination, soil aeration, pest control, and decomposition (Canales and Elder, 2020). Therefore, in addition to supporting biodiversity, it is in human's interest to preserve insects in order to keep our society functioning.

With the reinstatement of the rebate program and the looming drought, lawn removal is a critical step towards water conservation. Yet, there are still an abundance of green grass lawns throughout the local streets in Los Angeles County, and specifically Claremont. There are a number of analyses on the turf replacement program in Los Angeles and other participating water agencies in Nevada and Arizona (Sovocool, Morgan, Bennett, 2006; Medina et. al, 2015; Pincetl et al., 2017). Most of these analyses use data from the water district and focus on monetary savings from the replacement program (Medina et. al, 2015) or general landscape changes and spatial distribution around Los Angeles (Pincetl et al., 2017). We know that around 65,000 residents participated in the rebate program between 2014 and 2015 (Marx, 2021). Although the program is very popular, relatively few people participated and received rebates since Metropolitan Water District serves about 19 million people (Pincetl et al., 2017). So it is likely the majority of lawn replacement was not included in those studies, and we don't have any numbers on how common lawn replacement was in the broader population. Specifically for Claremont, an analysis with both MWD data and aerial data estimated that Claremont has 37 participants and 59.2 nonparticipants who converted from turf grass to alternative landscaping (Marx, 2021). This analysis is a start, but still leaves us with many unanswered questions. Thus, the main goal of this research is to identify and record trends and patterns among drought tolerant landscaping in Claremont using publicly available data from Google Maps.

Our goal was to address the following questions. First, how many houses have converted from lawn to alternative landscaping? What year did they convert? I expected that some years might have greater yard conversions due to more severe drought years or publicity by the water district. How much lawn has been replaced on average per home? And what kind of landscaping replaces the lawn? Understanding where and how many Claremont households have replaced lawns with drought tolerant landscaping will give us an idea of trends, urban local biodiversity, and next steps for environmental advocacy. Furthermore, we can estimate water savings using area data and average water usage estimates. We are also interested in spatial patterns of landscape changes around the city, since we anticipate that conversions may be unequally distributed around Claremont. This research is an important step towards evaluating Claremont’s sustainability footprint and will guide future conservation efforts in the context of water and biodiversity.

Materials and Methods

Study site:

We focused on Claremont, California, a town of approximately 37,000 people in the eastern edge of Los Angeles County covering approximately 13.35 square miles (34.6 km^2) (US census). Claremont has a Mediterranean climate, receiving most of its cool temperatures and rainfall between November and April. Between 1991 and 2020, the Claremont area had an average temperature of 65°F and received an average of about 14 inches of rain (NOAA). This is a decline from the 1948-1978 average of 17.93 inches (Bernard Field Station). Claremont's main supplier of water is the Golden State Water company which provides 60% of its water from local groundwater and imports the remaining 40% from Metropolitan Water District of Southern California (MWD) via Three Valleys Municipal Water District (Golden State Water). As such, residents of Claremont are eligible for participation in the MWD turf replacement rebate program.

Experimental Design:

We began by conducting a stratified random sample of houses in the Claremont area. We divided the city into four areas (Figure 1) by highway 210, highway 10, and route 66 which are main roads that run east to west in Claremont. These areas were selected because they roughly correspond with lot size and home property value (north Claremont corresponds with largest lot size and property value). Within each section, we listed and randomized all the east to west streets then selected non-corner houses along each street for sampling. By randomizing the streets within Claremont and selecting an equal number of houses in each section, we can account for variation in landscaping trends and variation in satellite and street-view imagery data.

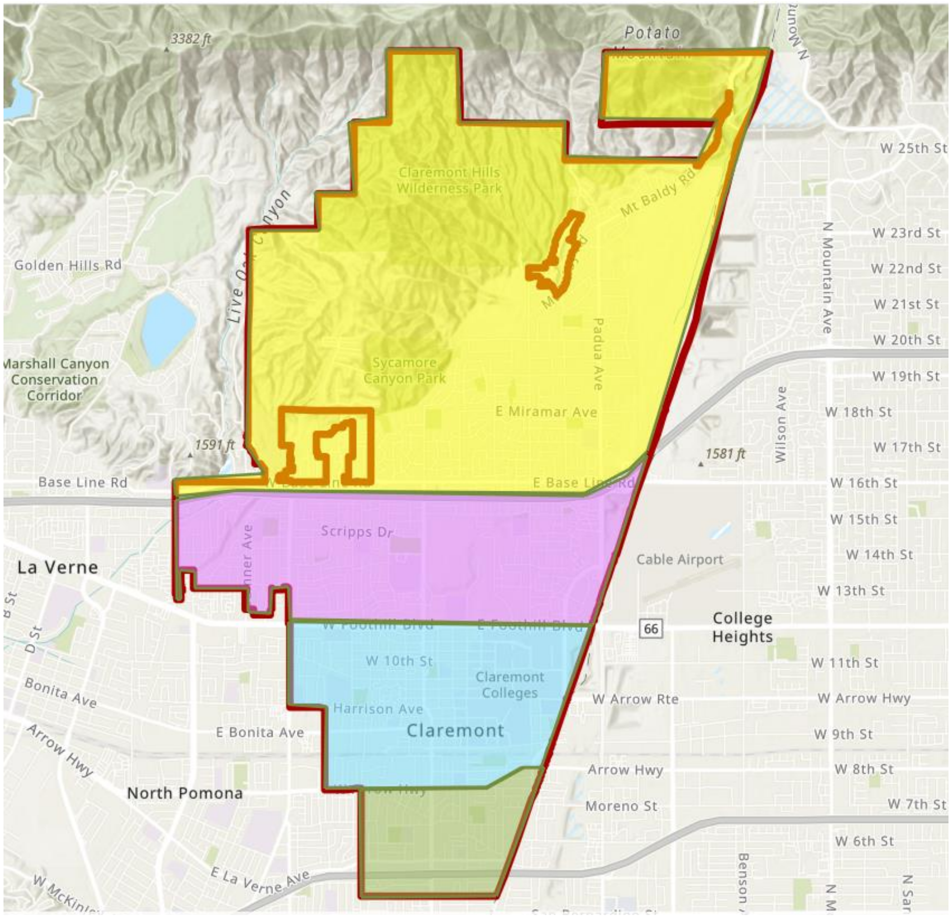

Figure 1: Yellow: North of US 210, Pink: US 66 to US 210, Blue: Arrow Highway to US 66, Green: South of Arrow Highway. We later designate North as including both yellow and pink regions and South as blue and green.

After selecting houses, use Google Earth satellite data (Figure 2) and Google Street View (Figure 3) to look at each house. We used the aerial view to draw polygons and measure areas, and street view to clarify details of landscaping not discernible from aerial images. For each house, we recorded the address, possible changes in yard landscaping, and current landscaping. Using the timeline tool on street view, we can view all the yard images that have been taken since 2007 and determine the accurate year of landscape change. Polygon measurements consisted of one main polygon of the front yard and smaller polygons for each major landscaping patch in the yard including turfgrass, gravel, mulch, herbaceous plants, shrubs, and impervious surfaces. For yards with patches of mixed landscaping features, we measured the polygon size then estimated the percent cover for the types of landscaping in each patch. If there is a change in the yard, we recorded polygon measurements for the most recent imagery before change (with lawn) and the most recent imagery of the house after the change.

For a select number of houses, we measured the yard perimeter on Google Earth then went to the house and measured the yard perimeter with tape measure to determine the accuracy. From a preliminary ground truthing we have found only a small difference between measurements, indicating that Google Earth is an accurate tool for measuring yard patch sizes (Table 1).

Polygon	Real Measurement (m)	Google Earth Measurement (m)	Percent error (%)
Front main patch	34.0	33.2	2.35
Sidewalk Median	28.7	28.5	0.70
Border left of driveway	27.6	26.7	3.26
Backyard Grass patch	36.4	34.6	4.95
Driveway	35.2	35.2	0

Table 1: Ground truthing data and Google Earth Data. We calculated percent error and found all to be less than 5% error.

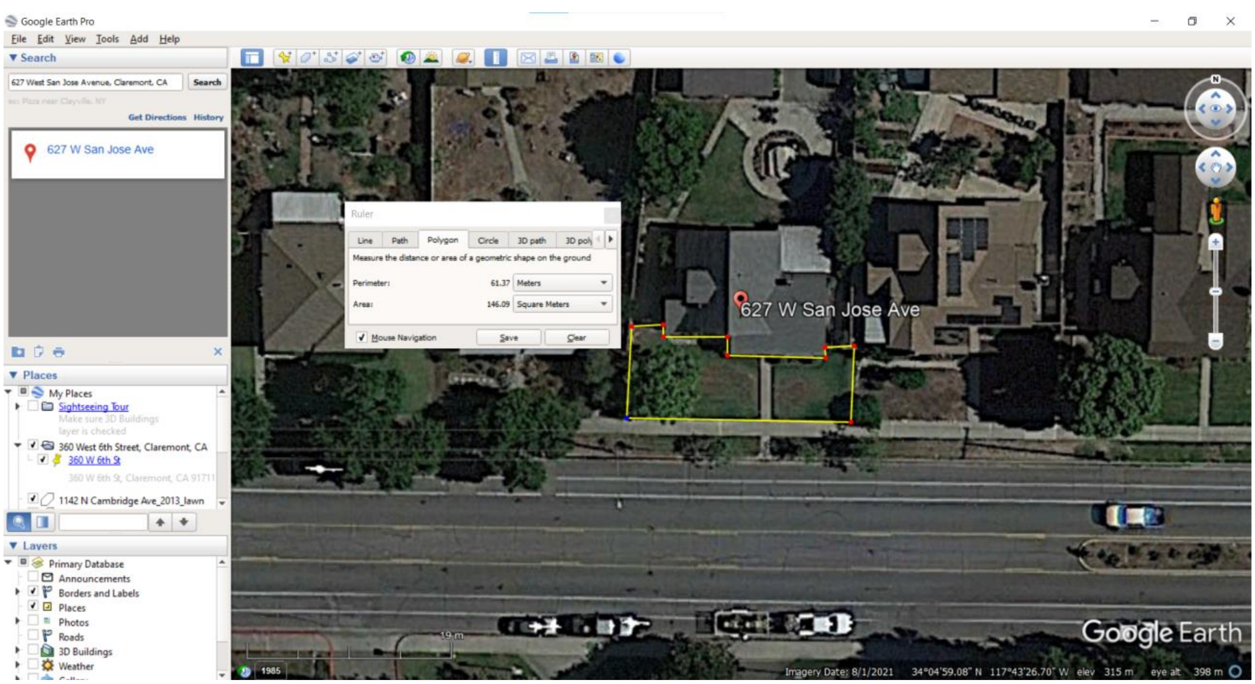

Figure 2: Google Earth view of house in Claremont. The polygon tool is used to measure the size of each yard.

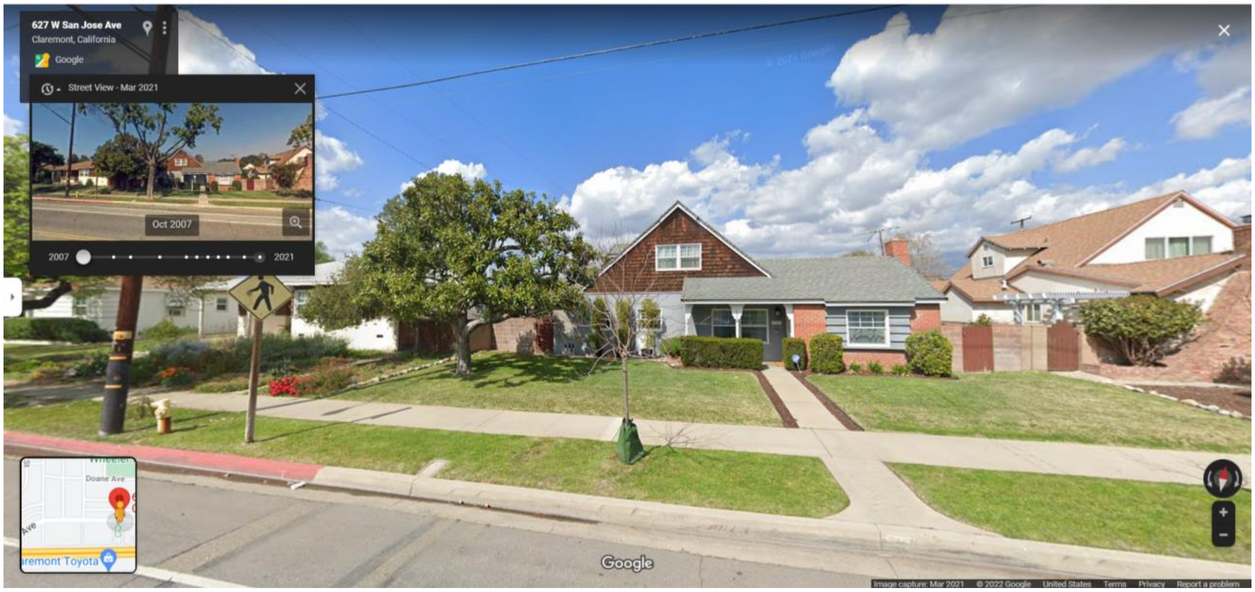

Figure 3: Street view of house in Claremont. The timeline in the top left corner shows past imagery. In this case it shows what the yard looked like in October, 2007.

Results

Overall, 46.75% (36 houses) had changes in landscaping and 53.25% (41 houses) did not change landscaping. Regionally (see figure 1 in Methods), we surveyed 25 houses in the North region and 60% (15 houses) had changes in landscaping. For the South region we surveyed 52 houses and found that 40% (21 houses) had changes in landscaping (Figure 4).

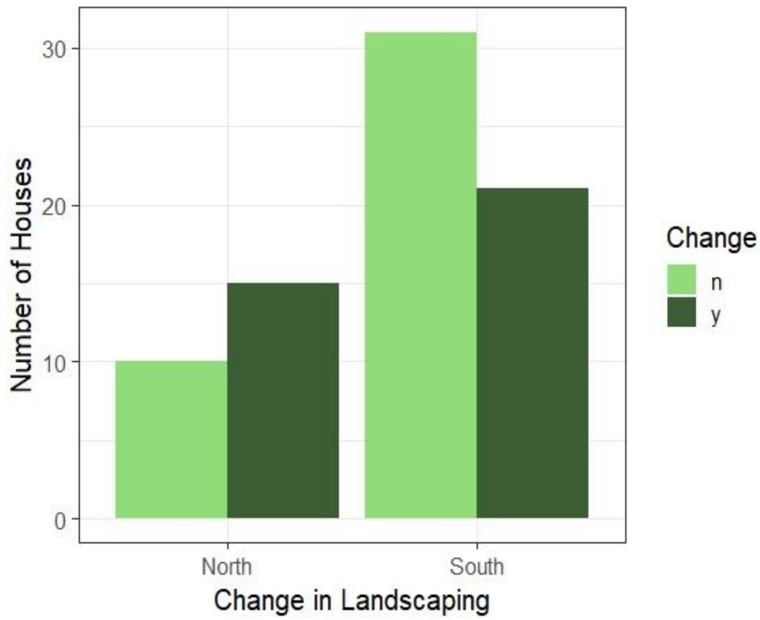

Figure 4: Change in landscaping graphed by region

By designating houses by region, we find the median yard size for the North region (242 m²) is larger than the South region (157.8 m²).

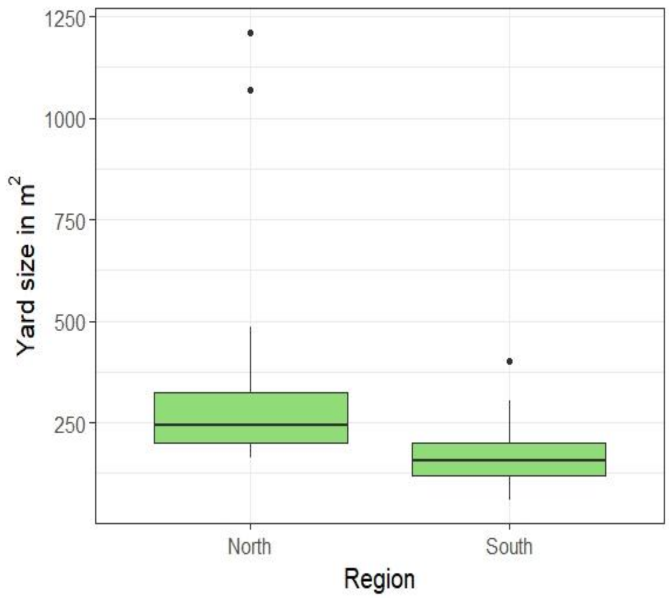

Figure 5: Boxplot of yard size by region. Median for North region (242 m²) is larger than the South region (157.8 m²).

We surveyed houses between 2007 and 2018. We did not find an association between the number of houses and the year of landscaping change ($X^2 = 1.88$, df = 1, p-value = 0.17).

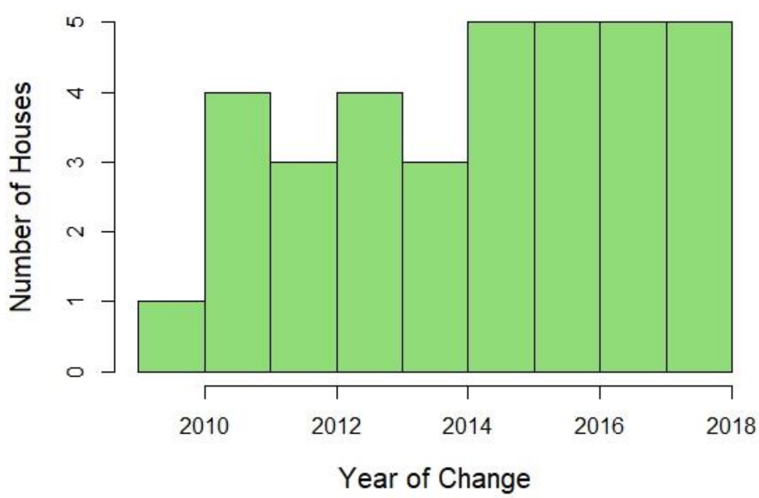

Figure 6: Histogram of the year that houses changed their landscaping. We did not find significance with the X^2 test, so we cannot claim association between the number of houses and the year of landscaping change ($X^2 = 1.88$, df = 1, p-value = 0.17).

For houses that did not change the landscaping, the mean amount of turf grass is 65.32 m² (SE: 8.13) and median is 49.25 m².

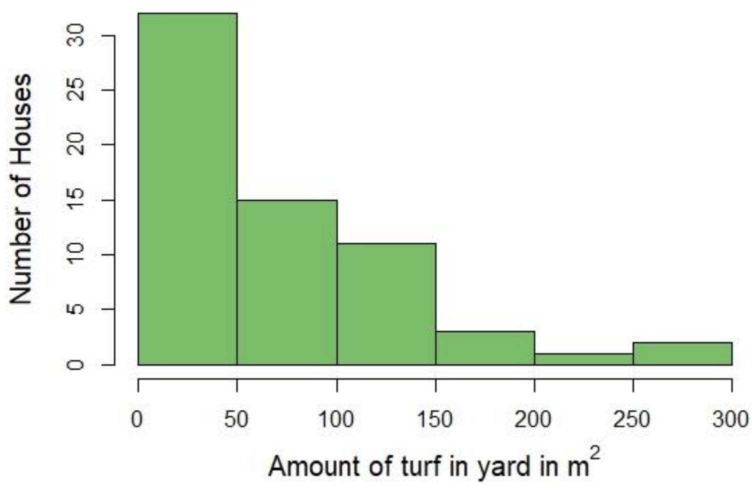

Figure 7: Histogram of amount of turf grass in yard, mean amount of turf grass is 65.32 m² and standard error 8.13.

For houses that did not change the landscaping, the mean proportion of turf grass area to yard area is 0.32 (SE: 0.036) and median: 0.24. This value was calculated this by dividing the area of the yard by the area of turf.

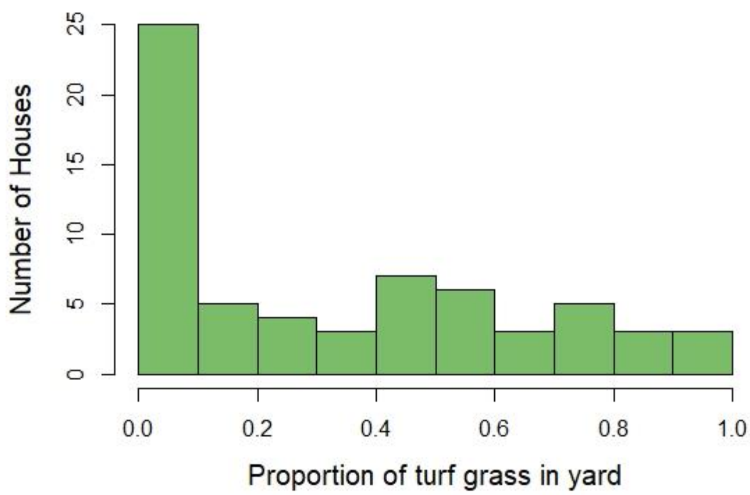

Figure 8: Histogram of the proportion of turf grass under yard. Most yards are not entirely turf with the mean being 0.32 and standard error 0.036.

We then designated the yards that changed their landscaping. For the yards that changed, the mean amount of turf grass removed is -65.23 m^2 (SE: 9.21 m^2) and median is -55.07 m^2. This was calculated by subtracting past turf area from new turf area. Since most houses removed all the turf grass, this value is negative. Only one house added more turf grass.

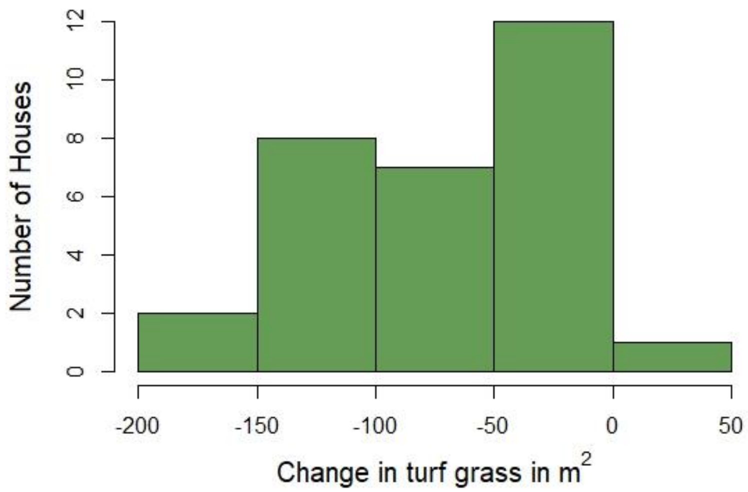

Figure 9: Histogram of the amount of turf grass removed from yards. The mean is -65.23 m^2 and standard error 9.21 m^2.

For houses that changed landscaping, the mean proportion of turf grass area removed to yard area is -0.35 (SE: 0.049) and median -0.33. This was calculated by dividing the yard area by the difference in past turf area and new turf area. The negative values indicate that houses have removed and not added!

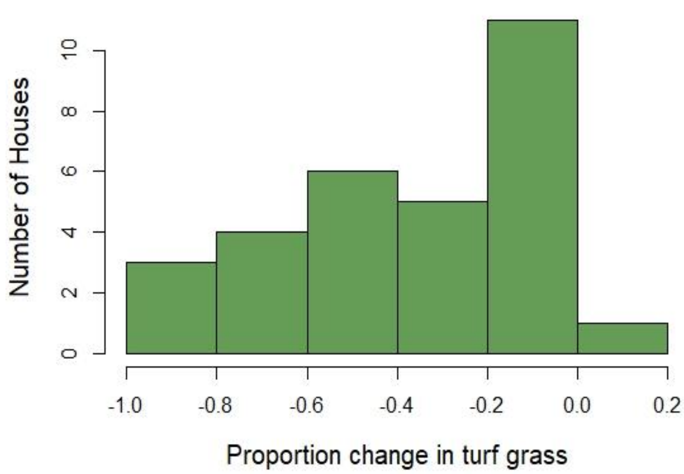

Figure 10: Histogram of the proportion of turf grass removed to yard area

The yards in the South region removed a greater proportion of their turf than yards in the North region (t = 3.5, df = 27.9, p-value = 0.0014).

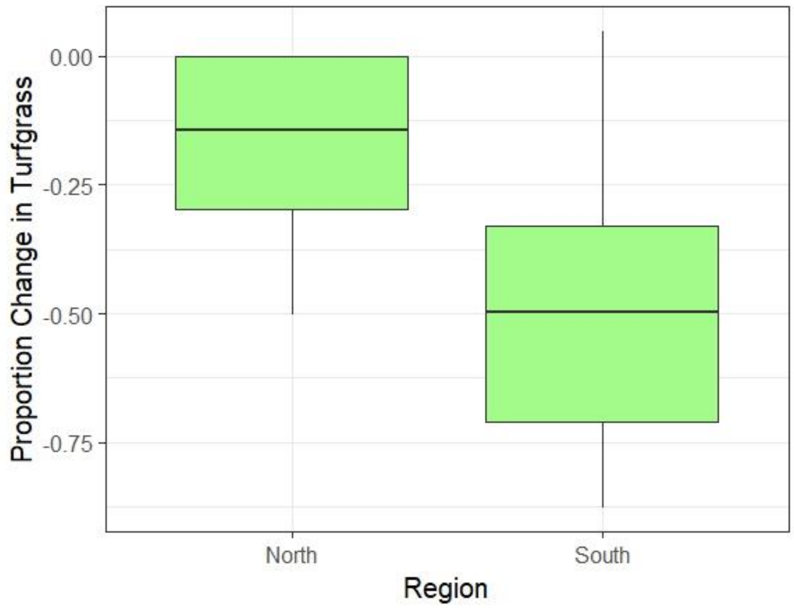

Figure 11: Mean north: -0.17, Mean south: -0.48

Mean predicted water savings for single-family residential households in California and Nevada are estimated at 24.6 gal/ft2/yr (264.8 gal/m2/year) from Tull, Schmitt, and Atwater (2016). We can use this to estimate how much water has been saved by landscape conversion.

The median area of turf grass removed is 55.07 m^2, so a household is saving ~14,581 gal/year. This is equivalent to: 486 bathtubs (30 gal/bath), 583 ten-minute showers (2.5 gal/min), 633 laundry loads (23 gal/load), or 2,430 dishwasher cycles (6 gal/wash). These water usage values are based on the EPA estimates on the Water Sense website. By choosing more water efficient appliances, households can save even more water, thereby reducing their environmental impact, and also saving money in water service charges and electricity.

Discussion

This project is the first analysis of landscaping patterns, trends, and changes in Claremont, California. Almost half of the houses surveyed have converted to alternative landscaping from turf grass between the years surveyed, 2007 and 2018. This indicates that Claremont residents are taking steps towards more sustainable living practices. As presented in the results section, the mean proportion of turf grass area to yard area for unchanged houses is 0.32 and for houses that changed landscaping, the mean proportion of turf grass area removed to yard area is -0.35. Put another way, the mean amount of turf grass in unchanged houses is 65.32 m^2 and for yards that changed, the mean amount of turf grass removed is -65.23 m^2. Although all yard sizes are not equal, many households are removing most or all of the turf grass in their yards. All together using the median area removed, the 36 houses that we surveyed are saving 524,916 gallons of water per year.

Interestingly, the turf grass removal was greater in the Southern than Northern region, despite Northern Claremont being associated with higher property value. We expected that houses with higher property value would have more landscape conversion because of higher income, and thus a smaller financial hardship is required. Since that is not the case, the trend of turf grass lawns is still dominant in these communities. While we did not interview households about their norms and beliefs in this study, this begs the question of: what is the value of lawns (in Claremont)? And are people questioning the social, symbolic, aesthetic, and ecological value of lawn in California and the general Western world? Marshall, Grose, and Williams describe that maintaining the lawn is considered a normative behavior, as a result of deeper social forces behind the well-tended lawn such as good morals, community mindedness, or even helping the environment (2020). As such, they found that the strength of normative behaviors (and conversely the perception of possible disapproval from neighbors) are the largest barrier to accepting alternative forms of landscaping (Marshall, Grose, and Williams, 2020). Therefore, one of the most important steps in encouraging drought tolerant and native plant landscaping is engaging homeowners, land managers, and other stakeholders in conversations about the environmental impact of turf grass. Of course, social norms and perceptions of lawns are not going to change overnight, but it will begin with education and demonstrating the beauty and value of native plants.

This research indicates that the City of Claremont should invest in public education and outreach, particularly to households in the Northern region. Apart from social norms, residents may not be aware of the ecological cost of lawn maintenance such as water usage and loss of biodiversity. Education can involve connecting residents out to contractors and landscape designers that work with native plants and hosting workshops in public places like libraries, farmers markets, or parks. Furthermore, Claremont can update and better advertise the MWD Turf Removal Program. Currently the city of Claremont website says that the program has been suspended even though Claremont residents are currently eligible for a rebate when they convert their yard to drought tolerant landscaping.

Claremont should more widely encourage the use of native plants. It was difficult to observe what plants households are installing due to the quality of Google Earth Imagery. However, it is apparent that many households who did convert their landscaping chose exclusively non-native herbaceous plants, or some non-native plants mixed with some native. Also, many households simply removed the lawn and replaced it with gravel or mulch as the dominant landscape feature. This agrees with Pincetl et al., who found that about 30% of the yards surveyed had woodchips and about 20% had gravel as the main landscape feature (2019). While this is an option that saves water in comparison to turf grass, these landscape options do not offer habitat to insects and other animals like native vegetation for pollinators or bare ground for bees.

The greenhouse gas emissions, also referred to as the carbon footprint, are a more and more common way of quantifying the human impact on the environment. In Los Angeles County and wider southern California, the dominant native habitat is California sage scrub. However, it has been reduced to less than 10% of its original distribution due to urban development (Caspi et al., 2017). This is critical, since California sage scrub soils have been shown to store 25% more carbon than soils in non-native grassland (Caspi et al., 2017). Understanding carbon storage or emissions in Southern California associated with turf grass is critical but remains poorly understood. Townsend-Small and Czimczik demonstrate that urban ornamental turf grass (as opposed to turf grass lawns for athletic fields) in Los Angeles have the possibility to sequester atmospheric carbon dioxide under the right management (2010). As such, the total global warming potential of ornamental lawns ranges from -108 g CO_2/m^2/year for the low fertilization scenario (10 g N /m^2/year) to +285 g CO_2/m^2/year for the high fertilizer scenario (75 g

N/m²/year) (Townsend-Small and Czimczik, 2010). By this estimate, the average turf area in an unchanged yard in Claremont, 65.32 m², has a global warming potential between -7,054 and +18,616 grams CO_2/yr. Thus, the carbon footprint associated with turf grass for one household might be relatively small, but for the entirety of the Los Angeles Basin represents a large amount of carbon emissions.

During this research project, we created a protocol to analyze changes in landscaping in the past decade with Google Earth and Google Street View. These two tools are free, easy to use, and have data available in many urban neighborhoods. This protocol can be applied to other cities to measure their landscaping patterns. However, Google imagery does have limitations. For example, some of the Street View imagery is out of date with the real time changes in yards or there are not many images to choose from. Much of the Google Earth aerial imagery was too blurry, causing us to have to skip that house. However, because of the color of turf grass, it was easy to identify when it was in a yard even if the imagery was poor quality. One of the other major limitations is difficulty identifying plants in the yard with Google imagery. Typically we used Street View imagery for this task rather than aerial imagery. Even so, it was hard to tell what plants were represented unless they were flowering or close to the street. Future data collection would benefit from recording this type of information in person.

One aspect of other analyses on landscaping in Southern California is that they have access to proprietary data from the Metropolitan Water District on participants in the rebate program. For example, Pincetl et al. used participant data in addition to Google Imagery to measure vegetation cover, species richness, and vegetation changes in participating households (2017). Additionally, Medina et al. used participant data to estimate the average household financial savings as a result of lawn removal (2015). Using MWD data and aerial analysis on GIS, Andrew Marx was able to study the “multiplier effect,” or the influence that participants have on their neighbors landscaping, finding a 132% conversion rate (2021). While our lack of MWD data can be seen as a disadvantage, it allowed us to analyze landscaping trends independent from financial motivation. Furthermore, we demonstrated that it is possible to measure and record this data using publicly available data. Our methods might be applicable to others looking to record landscaping trends in places without rebate programs or without participation data.

While we have presented an estimate of the annual water savings for households in Claremont, it must be noted that we are not actually monitoring people's watering habits. Therefore, with this qualification, households may be watering their gardens more (or less) than required and not meeting the estimate in this thesis. One reason people may water more than required is because California native plants dry up and go dormant in the summertime, giving off the appearance that they may be dead. However, California natives are special in that they have adapted to the unique Mediterranean climate, and they do not require extra watering in the summer. As such, education and outreach to Claremont regarding native California plants should describe this phenomenon as households embrace new landscaping, so they know how to properly care for their new garden and save water.

Further analysis on landscaping trends in Claremont might consider the multiplier effect, ground truth plant species in yards, measure carbon sequestration of soils under lawn versus drought tolerant landscaping, or conduct an economic cost-benefit analysis of removing lawns. The results from this analysis and any future analyses can be used to inform policy for the Metropolitan Water District as well as the City of Claremont. Knowledge of where landscape conversion is greatest can guide conservation efforts and outreach to the Claremont community. While indicative of California's seemingly endless drought-stricken condition, turf grass removal is a recognition that humanity must adapt to living in California's climate rather than the other way around.

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I acknowledge that I am currently residing and conducting research on the unceded land of the Tongva people. I recognize that the Tongva people were violently and forcibly removed from this area where we now conduct research and pursue knowledge. Science is used as a tool to justify oppression against Black, Indigenous, and people of color and undermine their right to life and their knowledge (Kean, 2019). I proceed with this senior thesis understanding that I have much to learn and will continue to educate myself and reflect on my privilege, especially as I promote the use of native plant species in urban landscaping. The societal expectation of grass lawns in yards across the United States is a physical manifestation of the "taming" of the indigenous ecosystem and asserting the unjust dominance of settler colonial aesthetics (Bousfield, 2020). Turfgrass lawns are actively harming native biodiversity and represent another failure of the colonial relationship to nature. As a young person in the field of environmental science, I recognize that long term goals of sustainable living or biodiversity conservation and restoration are not achieved without working to undo the injustices of settler colonialism.

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