Santa Monica Ecological Health Assessment

PROJECT REPORT

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I. Abstract

The City of Santa Monica adopted a Sustainability Ordinance in 2013 which states that residents have a right to a healthy environment. As part of the ordinance, the City evaluates the ecosystem health to inform environmental decision making. In this report, the City's ecological health is assessed using the parameters of tree canopy cover, land permeability, and biodiversity.

II. Introduction

The City of Santa Monica has made significant efforts to promote local sustainability. In 2013, the City adopted the Sustainability Rights Ordinance, recognizing the right to a clean, healthy environment, and setting a legal basis for protecting the local ecosystem. The City has engaged in a Sustainable City Plan for the last several decades, with the goal of "using the power of community to enhance our resources, prevent harm to the natural environment and human health, and benefit the social and economic wellbeing of the community for the sake of current and future generations" (Sustainable City Plan 2014). To track progress in providing sustainability rights, the City of Santa Monica publishes a Sustainability Rights Report every two years to assess the distribution of environmental benefits and to help inform policy decisions. To assist them in this endeavor, we evaluated Santa Monica's tree canopy coverage, permeable surfaces, and biodiversity.

We chose these three indicators to both build upon and expand the previous Sustainability Rights Report, comparing tree coverage data to the past report, and adding new analyses of permeability and biodiversity. In the last report, Santa Monica set a goal to preserve and increase the urban forest coverage; tree coverage is an essential environmental health indicator due to the environmental and public health benefits, from improving air and noise pollution to decreasing runoff (Driscoll et. al 2015, Stoffberg et. al 2010). However, the previous report did not have a land use or permeability analysis, so we used Los Angeles Region Imagery Acquisition Consortium (LARIAC) data to perform land classification and calculate the percentage of permeable surface in the City.

Permeable surfaces allow water percolation and infiltration, which is important for filtering out pollutants and recharging groundwater (University of Delaware, n.d.). Increasing permeable surfaces can improve stormwater management and better support the urban forest (Mullaney et. al 2015). Like permeability, biodiversity was not included in the previous report.

Additionally, we performed a biodiversity analysis due to the City's desire to expand their environmental health metrics, and the myriad benefits that come from species richness, such as aesthetics and increased resilience (Parris et. al 2018). Finally, we conducted these analyses for the City of Manhattan Beach to compare with the City of Santa Monica. We selected the City of Manhattan Beach because it shares many geographical, climatic, and economic similarities with the City of Santa Monica.

The City of Santa Monica set an intention to "protect, preserve, and restore" the natural habitat. For example, they joined almost 1,000 communities around the U.S. to reduce greenhouse gas emissions, with urban tree planting and forest maintenance as one of the main tenets of this agreement (Nowak et. al 2010). To improve the natural habitat, however, the City requires better monitors of environmental health, more detailed data, and continuous reports assessing progress.

The overall purpose of this analysis is to provide data, along with guidance and context, for the City of Santa Monica to prioritize ecosystem health and promote urban tree canopy health both citywide and in the areas that are most lacking in coverage. Not only will these consistent tools and analyses support Santa Monica's sustainability efforts, specifically through increasing permeable surfaces, urban tree canopy cover, and species richness, but they will provide a model for other cities around the country to engage and track sustainability efforts, so that we can move forward toward a more resilient future.

III. Methods

Tree Canopy Cover (California Forest Observatory)

Urban tree canopy (UTC) refers to "the layer of tree leaves, branches, and stems that provide tree coverage of the ground when viewed from above" and provides a method of measuring tree canopy cover in communities (USDA Forest Service, 2019). To evaluate tree canopy cover, we created choropleth maps depicting the percentage of tree canopy cover in the City of Santa Monica for the years of 2017 and 2020. The data was obtained from California Forest Observatory, a data-driven forest monitoring system developed by Salo Sciences, Inc. California Forest Observatory provides raster data at 10-meter spatial resolution for the entire

State of California for the years 2016-2020 and includes metrics such as canopy cover (percentage), canopy height (meters), and canopy bulk density (kg/m3) (California Forest Observatory, 2020). Tree canopy cover raster data is derived using airborne Light Detection and Ranging (LiDAR) data hosted by the USGS 3D Elevation Program, satellite imagery from Sentinel-1 C-band radar sensors and Sentinel-2 multispectral sensors, and deep learning models developed by Salo Sciences, Inc. to model tree canopy coverage statewide. For both 2017 and 2020, we used data from summer in order to remain consistent across years and estimate tree canopy at its maximum extent and fullness. Each pixel in the 10-meter resolution tree canopy cover raster data is assigned a percentage value of tree canopy cover from 0 to 100 percent. In terms of the California Forest Observatory tree canopy cover model performance, the model has an r-squared value of 0.91, meaning that the model correctly explains 91% of the tree canopy cover patterns. The model also has a mean absolute error (MAE) of 7.0%, meaning that tree canopy coverage predictions are, on average, within 7.0% of observed values (Salo Sciences, Inc., 2020).

In order to perform tree canopy coverage analysis for the City of Santa Monica, we accessed data from the California Forest Observatory site and analyzed the data in ArcGIS ArcMap (California Forest Observatory, 2020). The raster datasets covered the entire extent of Los Angeles County, so our first step was to extract the raster file to the extent of Santa Monica using a City Boundary (polygon) shapefile (City of Santa Monica, 2021). We extracted the California Forest Observatory data to cover the entire extent of the City, including the beach, following the extent used in the previous “Santa Monica Urban Tree Canopy Assessment” conducted by Dr. Qingfu Xiao (2018). With the rasters extracted to the Santa Monica boundary, our next step was to calculate the area of tree canopy cover in the City. The rasters are 10-meter resolution, so each pixel represents an area of 100 square meters. As mentioned earlier, each pixel is assigned a percentage value from 0 to 100, which translates to the percentage of each pixel that is covered by tree canopy. With these metrics, we were able to calculate the area of each pixel covered by tree canopy, and then sum these areas to obtain the total area of tree canopy in the City of Santa Monica. The citywide percentage of tree canopy cover was calculated by dividing the area of tree canopy cover by the area of Santa Monica. This analysis method was conducted for the City of Santa Monica for 2017 and 2020, and the same methodology was also used to calculate tree canopy cover for the City of Manhattan Beach in order to provide some context for comparison. A detailed step-by-step methodology can be found in the Appendix.

In addition to citywide tree canopy cover analysis, we also created exhibits showing the neighborhood breakdown of tree canopy cover for the City of Santa Monica in 2017 and 2020. To conduct this analysis, we loaded the extracted tree canopy cover dataset into ArcMap, along with the City of Santa Monica Neighborhood Organizations shapefile. Following the neighborhood breakdown used in the "Santa Monica Urban Tree Canopy Assessment" conducted by Dr. Qingfu Xiao (2018), we created separate polygon shapefiles for each neighborhood area. We then calculated the area of tree canopy and percentage of tree canopy within each neighborhood following the methods detailed in the previous paragraph. A detailed step-by-step methodology can be found in the Appendix.

Tree Canopy Cover (iTree)

Our practicum team used a second approach to calculate tree canopy coverage using iTree Canopy (iTree Canopy, 2021). While LiDAR provides greater accuracy in tree canopy coverage, iTree is able to calculate the economic benefits associated with coverage, such as air pollution, hydrological, and carbon benefits. iTree Canopy is a program that uses random satellite sampling in a defined location. We first used a shapefile of Santa Monica's city limits to create a boundary for sampling. After creating the boundary, we composed the land cover classes to be surveyed. The cover classes we used are: Tree/Shrub, Grass/Herbaceous, Impervious Buildings, Impervious Road, Impervious Other, Water, and Soil/Bare Ground. Tree/Shrub is the only cover class that is classified under tree cover. Monetary values of tree canopy coverage were assigned based on geographic location, so Santa Monica's values were determined by consideration of Los Angeles County's economy. The assets observed were air pollution, hydrological, and carbon benefits, and they consider metrics such as greenhouse gas removal annually, avoided runoff, and carbon sequestration and storage per year, to name a few. After calculation of environmental benefits, monetary values were assigned to these services. After the values were assigned, the survey was conducted using randomized sampling statistics by collecting random points within Santa Monica and assessing the cover class at each of these points.

We surveyed 1000 points within Santa Monica's city limits. We then uploaded this data into ArcGIS Online as a csv file for contextualization. To conduct our comparison city's survey, we repeated this analysis for the City of Manhattan Beach. Manhattan Beach also falls under Los Angeles County, so the monetary values assigned to the tree canopy services are the same.

Permeability Evaluated with Los Angeles Region Imagery Acquisition Consortium (LARIAC) Data

To evaluate permeability, we analyzed the land cover types and proportion of permeable areas in the City of Santa Monica for the years of 2014 and 2017. We used digital aerial imagery data from the Los Angeles Region Imagery Acquisition Consortium (LARIAC) Program, specifically LARIAC 4 data from 2014 and LARIAC 5 data from 2017 (County of Los Angeles, n.d.). LARIAC 4 and LARIAC 5 data consist of orthoimagery of Los Angeles County at 4 inch and 1 foot pixel resolution captured and processed by Pictometry International Corp (Los

Angeles County et al., 2015; Los Angeles County et al., 2018). The LARIAC 4 data also includes land cover classification performed by GroundPoint Technologies, LLC (Houston, 2016). Our team obtained LARIAC 4 data from Los Angeles County and LARIAC 5 data from the UCLA Library Data Science Center.

In order to perform 2014 tree canopy coverage analysis for the City of Santa Monica, we first loaded the 2014 LARIAC 4 land cover raster in ArcGIS ArcMap and extracted the raster to match the City of Santa Monica boundaries. The land cover raster includes seven classes – tree canopy, grass/shrubs, bare soil, tall shrubs, buildings, roads/railroads, and other paved areas – and each pixel is assigned a specific class. We calculated the area of each land cover type by multiplying the number of pixels associated with each class by the area of each pixel. We then added together the areas associated with tree canopy, grass/shrubs, bare soil, and tall shrubs to estimate the permeable area in the City, and added the areas associated with buildings, roads/railroads, and other paved areas to estimate the impermeable area in the City. To calculate the final proportion of permeable and impermeable area, we divided the corresponding areas by the total area of Santa Monica. A detailed step-by-step methodology can be found in the Appendix. We were not able to replicate this methodology for the City of Manhattan Beach because we were unable to access 2014 LARIAC 4 land cover data for Manhattan Beach.

Land cover data is not available in the 2017 LARIAC 5 dataset, so our team used a different methodology for estimating the permeable area in the City. We downloaded LARIAC 5 imagery tiles from the UCLA Library Data Science Center, ensuring the tiles covered the full extent of the City of Santa Monica. We opened these raster imagery tiles in ArcGIS ArcMap, merged all the tiles into one single raster using the Mosaic to New Raster tool, and then extracted the raster to the City of Santa Monica boundaries. With the LARIAC 5 imagery now only covering Santa Monica, we used the Image Classification tool in ArcGIS to perform land classification on the image. We decided to focus our sampling on five land cover types: vegetation, water, sand, roads, and buildings. Using the Image Classification tool, we recorded about one-hundred samples of each land cover type by drawing rectangles within each land cover type and assigning each rectangle to a specific class. We then performed a Maximum Likelihood Classification using our land cover samples as a guide. The output was a classified image with pixel values associated with each land cover class. We calculated the area of each land cover type by multiplying the number of pixels associated with each class by the area of each pixel. We then added together the areas associated with vegetation, sand, and water to estimate the permeable area in the City, and added the areas associated with buildings and roads to estimate the impermeable area in the City. To calculate the final proportion of permeable and impermeable area, we divided the corresponding areas by the total area of Santa Monica, 8.416 square miles. We then replicated this methodology for the City of Manhattan Beach in order to provide some context for comparison. A detailed step-by-step methodology can be found in the Appendix.

Species Richness (iNaturalist)

To evaluate biodiversity, we created a species richness heat map of Santa Monica. The data was obtained from iNaturalist; iNaturalist is a community science platform that allows users to take photos of various organisms, from plants to birds to insects and fungus, and scientists can then verify and identify the observations. For the purposes of our analysis, we limited our data to "research grade" or only those observations that had been verified by approved scientists on the platform. Additionally, we limited our data to observations from the last two full years (2019 - 2021) to represent a fairly current state of the species diversity in the City.

The iNaturalist data was downloaded from the Global Biodiversity Information Facility (GBIF) website, which hosts the observations from various community science platforms like iNaturalist (GBIF.org, 2021). There, we were also able to limit our data to observations with a location certainty within 30 meters, meaning any observations that did not have precise enough coordinates were disqualified. This was done to increase the accuracy of our final product. After these filters were applied, we had a total of 621 data points to be analysed.

We utilized the software QGIS, a map making application, for our analysis. A fully detailed step-by-step methodology can be found in the Appendix. First, we clipped the downloaded data points to just within the boundaries of the City of Santa Monica, using a vector file available on the LA County eGIS website (Los Angeles County, 2021). Then, we created a fishnet, essentially a grid of points across the entire city, and matched these points to our data. This gave us the ability to divide the data into different sized resolutions. We settled on a total of 150 boxes, approximately 38 acres each, to represent the species richness across all 5,400 acres of land in Santa Monica.

This analysis was completed with the help of Dr. Levi Simons, a Postdoctoral Scholar at UCLA, who provided the methodology for creating the heat maps. With his help and experience with creating similar maps, we also decided on the size of the boxes, as it provides a balance of detail while also being able to provide information for more neighborhood scale assessments. At smaller resolutions, the output becomes too vague, and at larger resolutions, the output is essentially just a scatter of points from the observation data. The boxes are colored based on the amount of unique species that have been observed in their bounds. This process was then repeated for the City of Manhattan Beach to provide a comparison for our analysis.

IV. Results

Tree Canopy Cover (California Forest Observatory)

Figures 1 and *2* show the area and percentage of tree canopy cover using the California Forest Observatory data in the City of Santa Monica for 2017 and 2020, respectively. In 2017, 1.14 square miles were covered by tree canopy, representing 13.6% of Santa Monica. In 2020, 1.13 square miles were covered by tree canopy, representing 13.4% of Santa Monica. From 2017 to 2020, there was a very slight (-0.2%) drop in tree canopy cover in the City of Santa Monica. Since the model employed by California Forest Observatory has a mean absolute error (MAE) of 7.0%, meaning that tree canopy coverage predictions are within 7.0% of observed values, the 0.2% drop between 2017 and 2020 may not be a significant decrease (Salo Sciences, Inc., 2020).

Figure 1. City of Santa Monica Tree Canopy Cover in 2017.

Figure 2. City of Santa Monica Tree Canopy Cover in 2020.

Similarly, *Figures 3* and *4* depict the area and percentage of tree canopy cover in the City of Manhattan Beach for 2017 and 2020, respectively, using California Forest Observatory data. In 2017, 0.55 square miles were covered by tree canopy, representing 13.9% of Manhattan Beach. In 2020, 0.52 square miles were covered by tree canopy, representing 13.2% of Manhattan Beach. From 2017 to 2020, there was a slight (-0.7%) drop in tree canopy cover in the City of Manhattan Beach.

The proportion of tree canopy cover in the City of Santa Monica and the City of Manhattan Beach is very similar, with both between 13% and 14%. Between 2017 and 2020, the City of Manhattan Beach exhibits a slightly larger drop in the percentage of tree canopy cover than the City of Santa Monica. Tree canopy cover decreases by 0.2% in Santa Monica between 2017 and 2020, while tree canopy cover decreases by 0.7% in Manhattan Beach. However, since the decreases in both cities are within the mean absolute error of the California Forest Observatory model (7.0%), the drops in tree canopy coverage are likely too slight to be considered significant (Salo Sciences, Inc., 2020).

Figure 3. City of Manhattan Beach Tree Canopy Cover in 2017.

Figure 4. City of Manhattan Beach Tree Canopy Cover in 2020.

Figures 5 and *6* depict the area and percentage of tree canopy cover within each neighborhood in the City of Santa Monica for 2017 and 2020, respectively. *Tables 1* and *2* show the raw data associated with neighborhood tree canopy cover. *Figure 7* plots the change in tree canopy cover within Santa Monica neighborhoods over time. In both years, the percent of tree canopy cover ranged from ~9% in the Pico Neighborhood Association area to ~22% in the North of Montana Association neighborhood. The neighborhoods with the highest tree canopy cover, North of Montana Association and Northeast Neighbors Association, showed a further increase in canopy cover from 2017 to 2020, while the neighborhood with the lowest tree canopy cover, Pico Neighborhood Association, showed a further decrease in canopy cover from 2017 to 2020. There was an increase in tree canopy cover in four neighborhood areas and a decrease in tree canopy cover in five neighborhood areas. The northernmost and southernmost portions of the City have the highest proportions of tree canopy cover, while the inner portions of the City have the lowest proportions of tree canopy cover.

Table 1. 2017 Santa Monica Neighborhood Tree Canopy Cover.

Neighborhood	**Tree Canopy in m^2**	**Tree Canopy in km^2**	**Neighborhood Area in km^2**	**% Tree Canopy Cover**
North of Montana Association	842,290	0.84229	3.91	21.54%
Northeast Neighbors Association	204,766	0.204766	1.16	17.65%
Friends of Sunset Park	732,444	0.732444	4.82	15.20%
Unassigned Neighborhood Area	71,113	0.071113	0.55	12.93%
Wilshire/Montana Neighborhood Coalition	259,416	0.259416	2.43	10.68%
Ocean Park Association	202,942	0.202942	1.94	10.46%
Santa Monica Mid-City Neighbors	189,065	0.189065	1.90	9.95%
Overlap Area	57,055	0.057055	0.58	9.84%
Pico Neighborhood Association	422,497	0.422497	4.45	9.49%

Figure 5. 2017 Santa Monica Neighborhood Tree Canopy Cover.

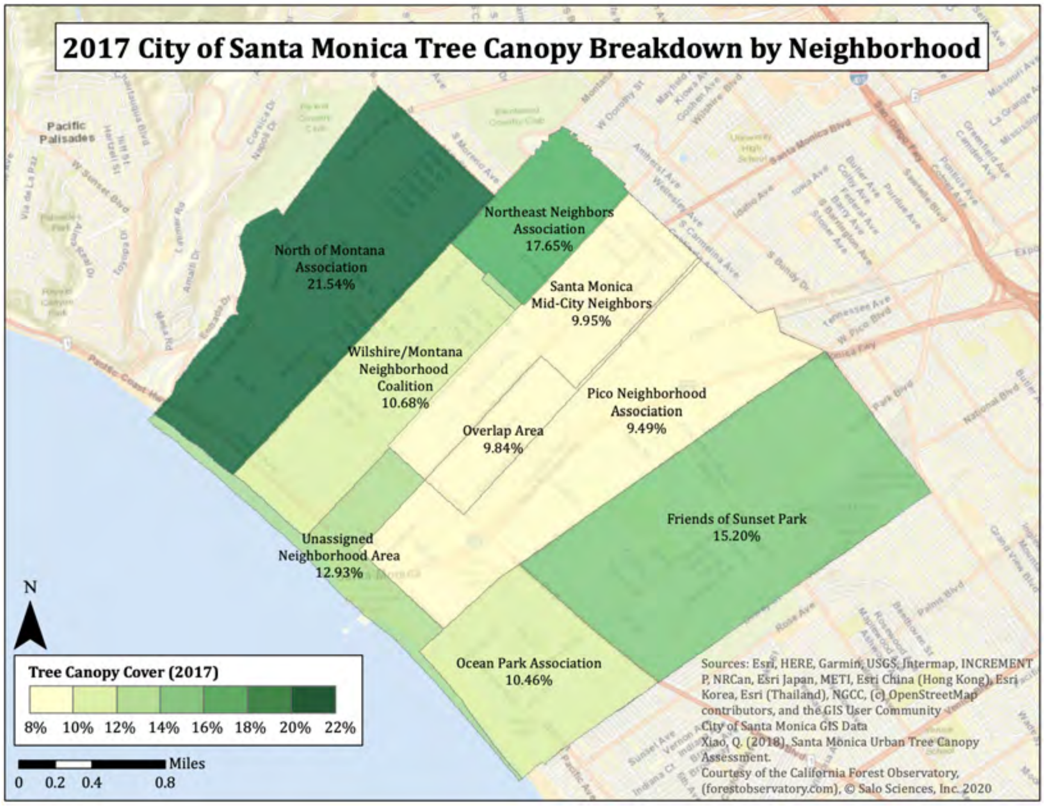


Table 2. 2020 Santa Monica Neighborhood Tree Canopy Cover.

Neighborhood	Tree Canopy in m^2	Tree Canopy in km^2	Neighborhood Area in km^2	% Tree Canopy Cover
North of Montana Association	856,278	0.856278	3.91	21.90%
Northeast Neighbors Association	220,290	0.22029	1.16	18.99%
Friends of Sunset Park	701,441	0.701441	4.82	14.55%
Unassigned Neighborhood Area	62,010	0.06201	0.55	11.27%
Santa Monica Mid-City Neighbors	198,124	0.198124	1.90	10.43%
Ocean Park Association	197,170	0.19717	1.94	10.16%
Overlap Area	58,915	0.058915	0.58	10.16%
Wilshire/Montana Neighborhood Coalition	242,678	0.242678	2.43	9.99%
Pico Neighborhood Association	405,779	0.405779	4.45	9.12%

Figure 6. 2020 Santa Monica Neighborhood Tree Canopy Cover.

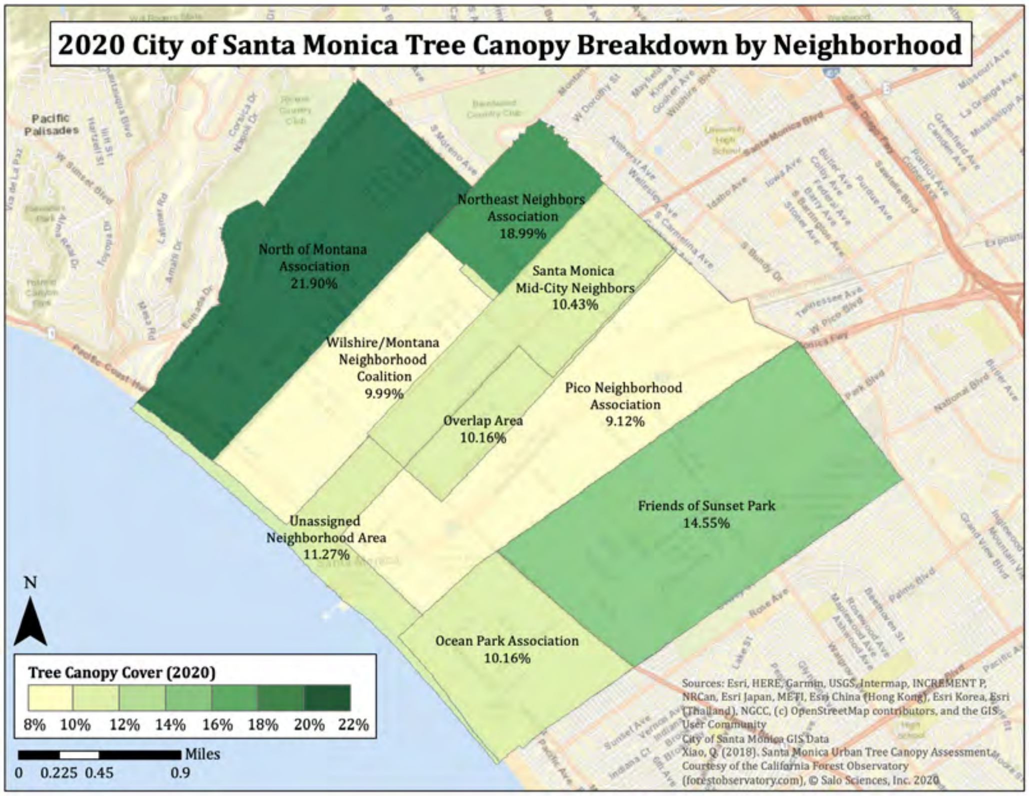
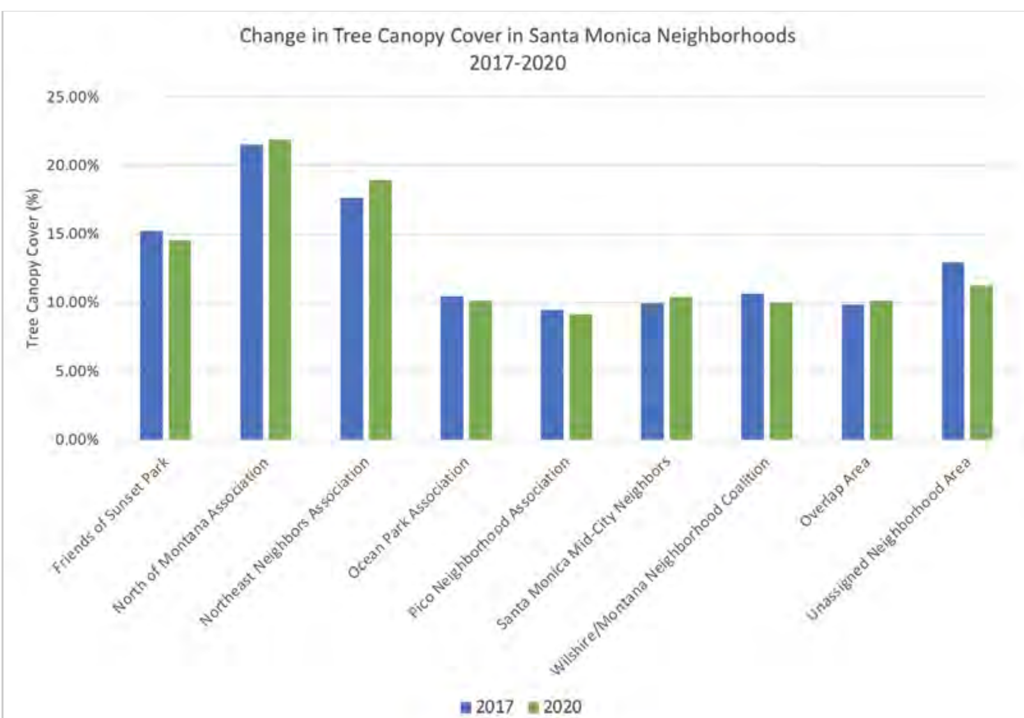


Figure 7. Change in Tree Canopy Cover in Santa Monica Neighborhoods.



Tree Canopy Cover (iTree)

Figure 8 depicts the city limits of Santa Monica with the 1000 survey points used to classify land coverage. *Figure 9* shows the distribution of these classes, and *Table 3* shows these exact values. *Tables 4, 5,* and *6* show the economic benefits of the ecosystem services provided by this amount of tree coverage.

Figure 10 is a map depicting the city limits of Manhattan Beach with the 1000 survey points used to classify land coverage. *Figure 9* shows the distribution of these classes, and *Table 7* shows these exact values. *Tables 8, 9,* and *10* show the economic benefits of the ecosystem services provided by this amount of tree coverage.

Figure 8: Santa Monica Survey of Land Coverage.

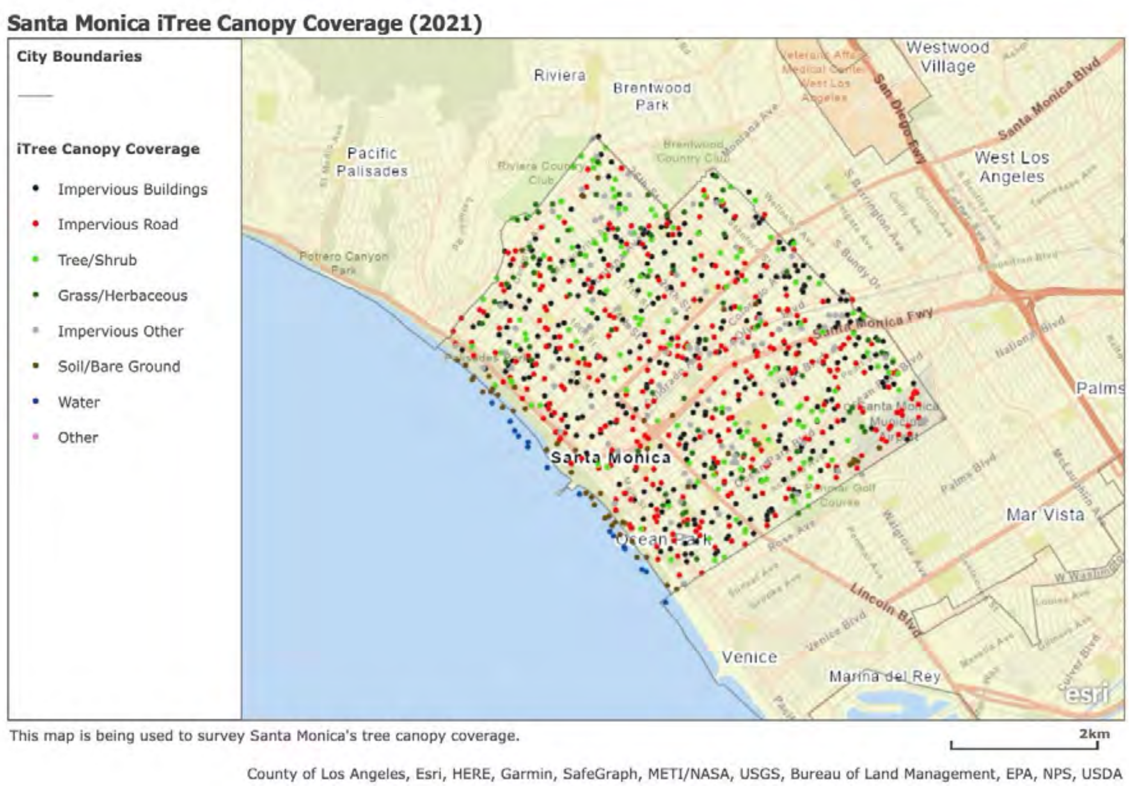


Figure 9: Percent and Area of Land Cover Classes in Santa Monica.

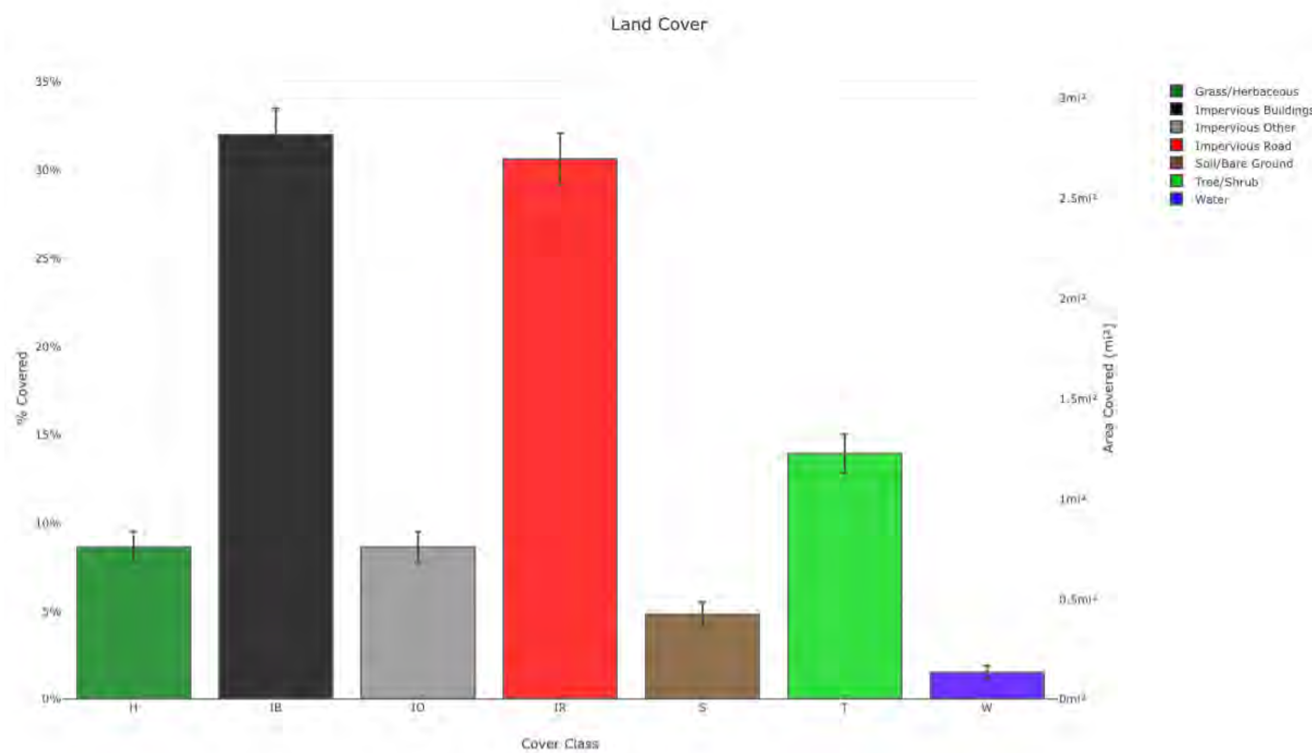


Table 3: Land Cover Classification of Santa Monica.

Cover Class	Points	% Cover	Area (mi²)
Grass/Herbaceous	86	8.60 ± 0.89	0.76 ± 0.08
Impervious Buildings	320	32.00 ± 1.48	2.82 ± 0.13
Impervious Other	86	8.60 ± 0.89	0.76 ± 0.08
Impervious Road	306	30.60 ± 1.46	2.70 ± 0.13
Soil/Bare Ground	48	4.80 ± 0.68	0.42 ± 0.06
Tree/Shrub	139	13.90 ± 1.09	1.23 ± 0.10
Water	15	1.50 ± 0.38	0.13 ± 0.03
Total	1000	100.00	8.82

Table 4: Annual Tree Benefit Estimates of Air Pollution in Santa Monica.

Description	Amount (lb)	Value (USD)
Carbon Monoxide removed annually	1,991.41 ± 156.73	$256 ± 20
Nitrogen Dioxide removed annually	15,940.73 ± 1,254.59	$1,337 ± 105
Ozone removed annually	68,615.85 ± 5,400.31	$71,082 ± 5,594
Sulfur Dioxide removed annually	4,290.53 ± 337.68	$85 ± 7
Particulate Matter < 2.5 microns removed annually	1,653.78 ± 130.16	$18,592 ± 1,463
Particulate Matter > 2.5 microns and < 10 microns removed annually	11,432.66 ± 899.79	$10,457 ± 823
Total	**103,924.96 ± 8,179.26**	**$101,808 ± 8,013**

Table 5: Hydrological Tree Benefit Estimates in Santa Monica.

Description	Amount (Mgal)	Value (USD)
Avoided Runoff	2.64 ± 0.21	$23,623 ± 1,859
Evaporation	36.32 ± 2.86	n/a
Interception	36.33 ± 2.86	n/a
Transpiration	142.09 ± 11.18	n/a
Potential Evaporation	588.28 ± 46.30	n/a
Potential Evapotranspiration	513.84 ± 40.44	n/a

Table 6: Tree Benefit Estimates of Carbon in Santa Monica.

Description	Carbon (kT)	CO_2 Equiv. (kT)	Value (USD)
Sequestered annually in trees	1.36 ± 0.11	4.99 ± 0.39	$232,248 ± 18,279
Stored in trees (this benefit is not an annual rate)	26.90 ± 2.12	98.64 ± 7.76	$4,588,124 ± 361,101

Figure 10: Manhattan Beach Survey of Land Coverage.

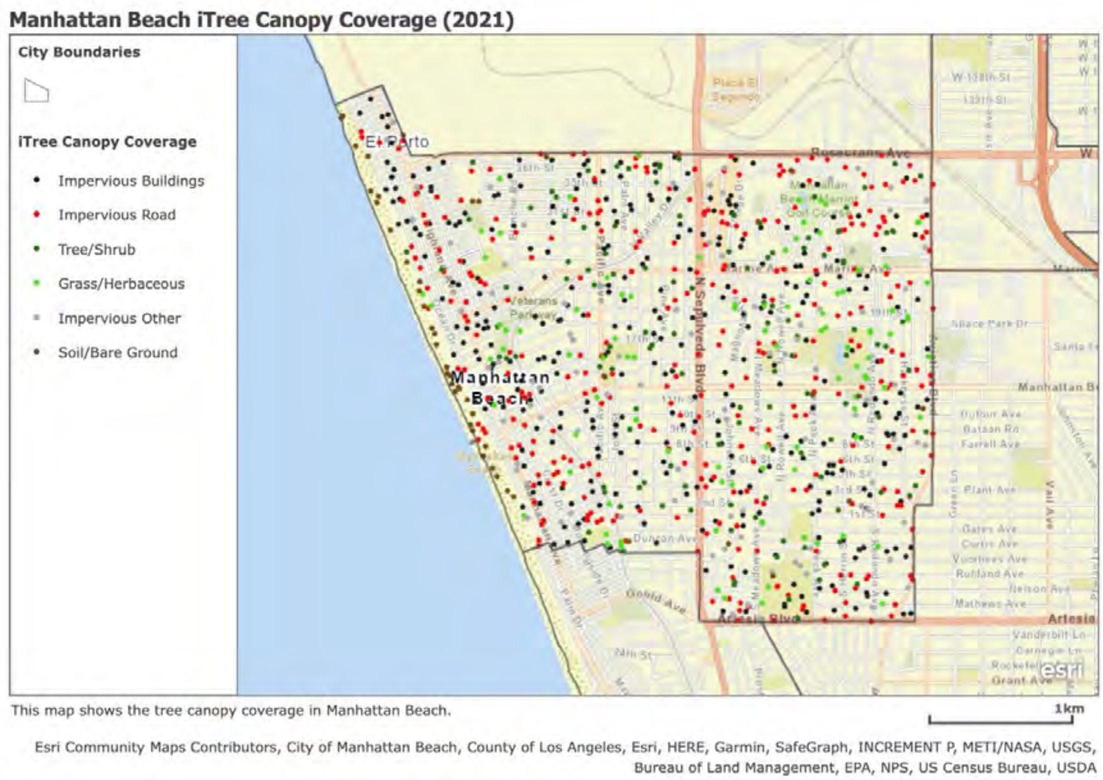


Figure 11: Percent and Area of Land Cover Classes in Manhattan Beach.

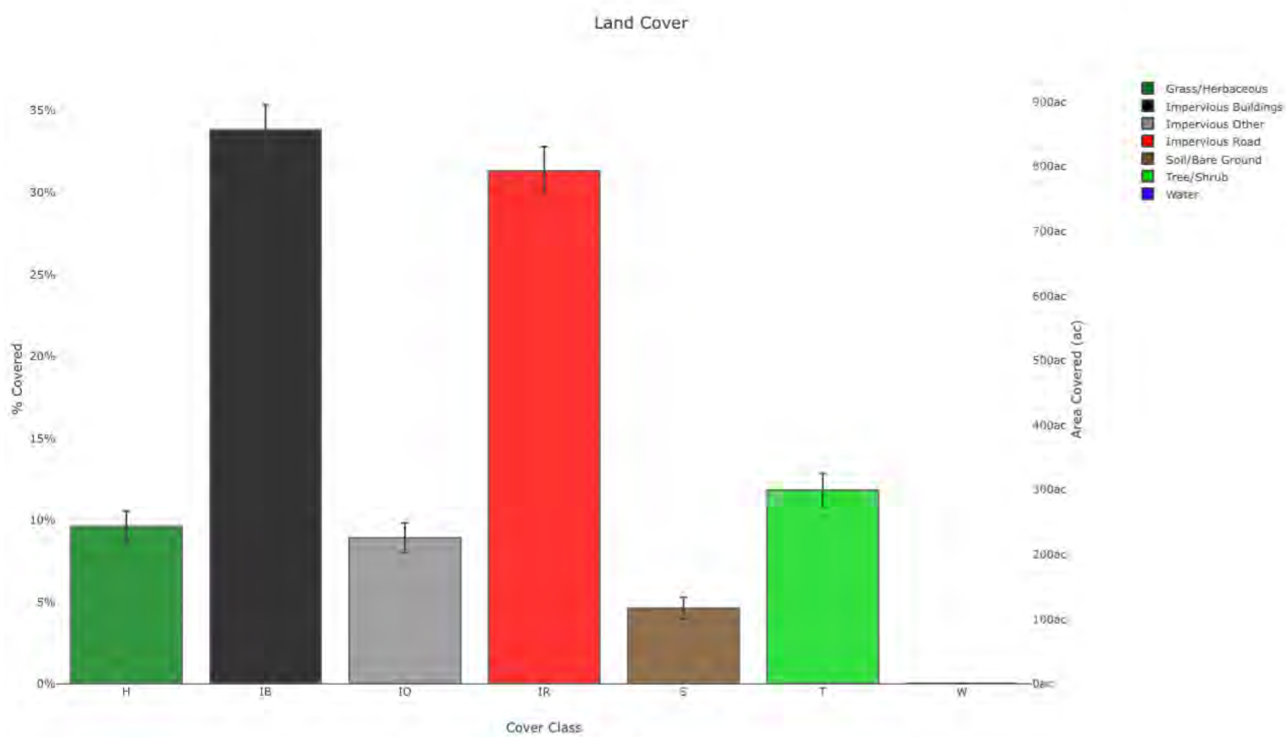


Table 7: Land Cover Classification of Manhattan Beach.

Cover Class	**Points**	**% Cover**	**Area (ac)**
Grass/Herbaceous	96	9.60 ± 0.93	243.11 ± 23.59
Impervious Buildings	338	33.80 ± 1.50	855.95 ± 37.88
Impervious Other	89	8.90 ± 0.90	225.38± 22.80
Impervious Road	313	31.30 ± 1.47	792.64 ± 37.13
Soil/Bare Ground	46	4.60 ± 0.66	116.49 ± 16.78
Tree/Shrub	118	11.80 ± 1.02	298.82 ± 25.83
Water	0	0.00 ± 0.00	0.00 ± 0.00
Total	1000	100.00	2532.40

Table 8: Annual Tree Benefit Estimates of Air Pollution in Manhattan Beach.

Description	**Amount (lb)**	**Value (USD)**
Carbon Monoxide removed annually	758.31 ±65.56	$97 ± 8
Nitrogen Dioxide removed annually	6,070.11 ± 524.79	$509 ± 44
Ozone removed annually	26,128.38 ± 2,258.95	$27,068 ± 2,340
Sulfur Dioxide removed annually	1,633.80 ± 141.25	$32 ± 3
Particulate Matter < 2.5 microns removed annually	629.75 ± 54.45	$7,080 ± 612
Particulate Matter > 2.5 microns and < 10 microns removed annually	4,353.47 ± 376.38	$3,982 ± 334
Total	**39,573.81 ± 3,421.38**	**$38,768 ± 3,352**

Table 9: Hydrological Tree Benefit Estimates in Manhattan Beach.

Description	**Amount (Mgal)**	**Value (USD)**
Avoided Runoff	1.01 ± 0.09	$8,995 ± 778
Evaporation	13.83 ± 1.20	n/a
Interception	13.83 ± 1.20	n/a

Transpiration	54.11 ± 4.68	n/a
Potential Evaporation	224.01 ± 19.37	n/a
Potential Evapotranspiration	195.67 ± 16.92	n/a

Table 10: Tree Benefit Estimates of Carbon in Manhattan Beach.

Description	Carbon (T)	CO_2 Equiv. (T)	Value (USD)
Sequestered annually in trees	518.54 ± 44.83	1,901.33 ± 164.38	$88,438 ± 7,646
Stored in trees (this benefit is not an annual rate)	10,244.00 ± 885.65	37,561.33 ± 3,247.39	$1,747,121 ± 151,048

Permeability Evaluated with Los Angeles Region Imagery Acquisition Consortium (LARIAC) Data

Figure 12 maps the land cover types in the City of Santa Monica in 2014, using LARIAC 4 data. Buildings make up the largest land cover type (27.38%), followed by tree canopy (21.15%) and other paved surfaces (18.33%). The land cover types that make up the smallest area in the City are bare soil (4.82%) and tall shrubs (0.0024%). *Figure 13* depicts the permeable (tree canopy, tall shrubs, grass/shrubs, bare soil) and impermeable (buildings, roads/railroads, other paved) area in Santa Monica in 2014. Permeable area represents 38.78% of the City, while impermeable area represents 61.22% of the City.

Figure 12. Land Cover Types in the City of Santa Monica in 2014.

Figure 13. Permeability in the City of Santa Monica in 2014.

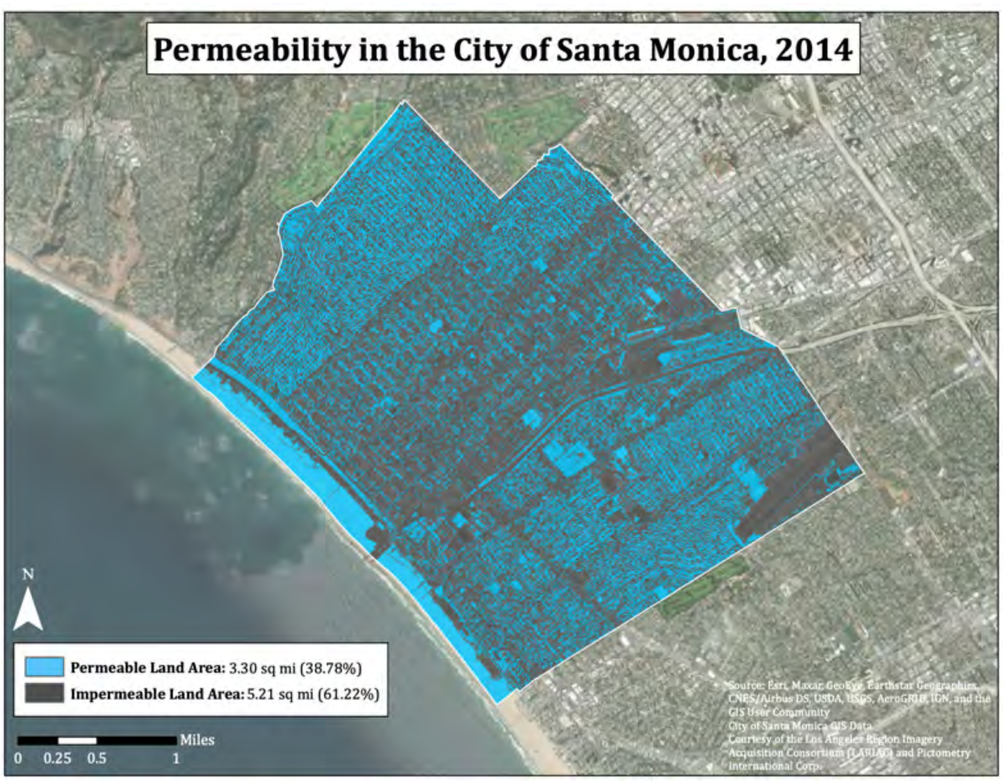
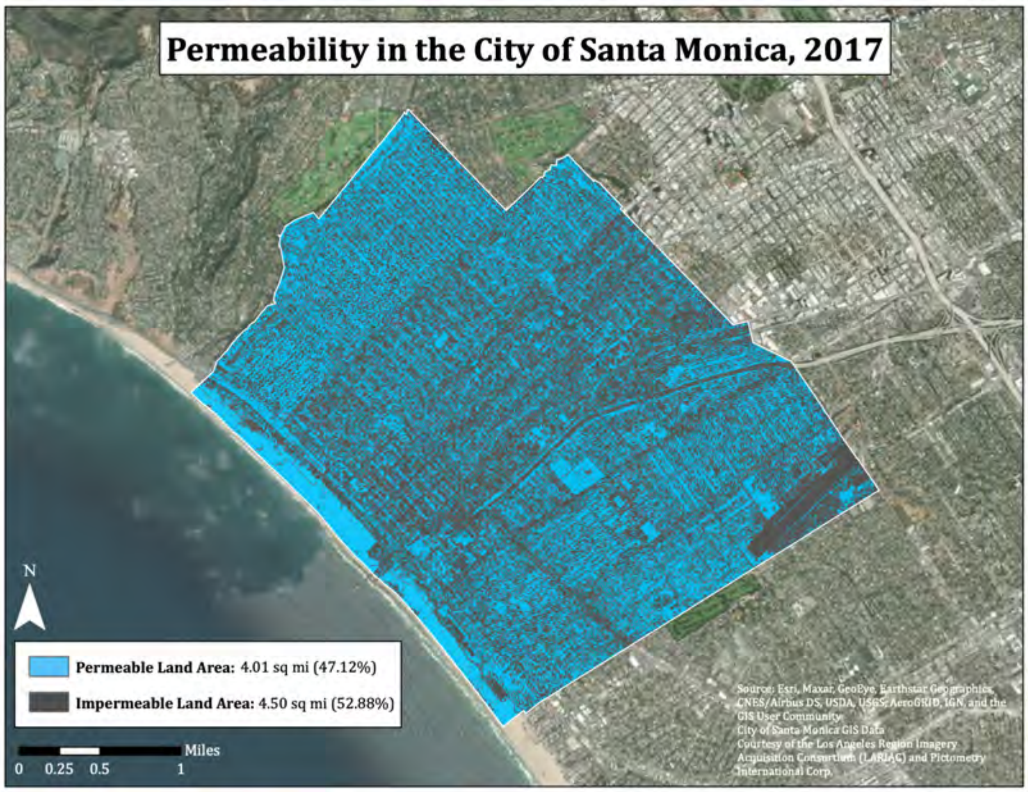


Figure 14 depicts the permeable (vegetation, sand, water) and impermeable (buildings, roads) area in Santa Monica in 2017, derived from LARIAC 5 data through land classification. Permeable area represents 47.12% of the City, while impermeable area represents 52.88% of the City.

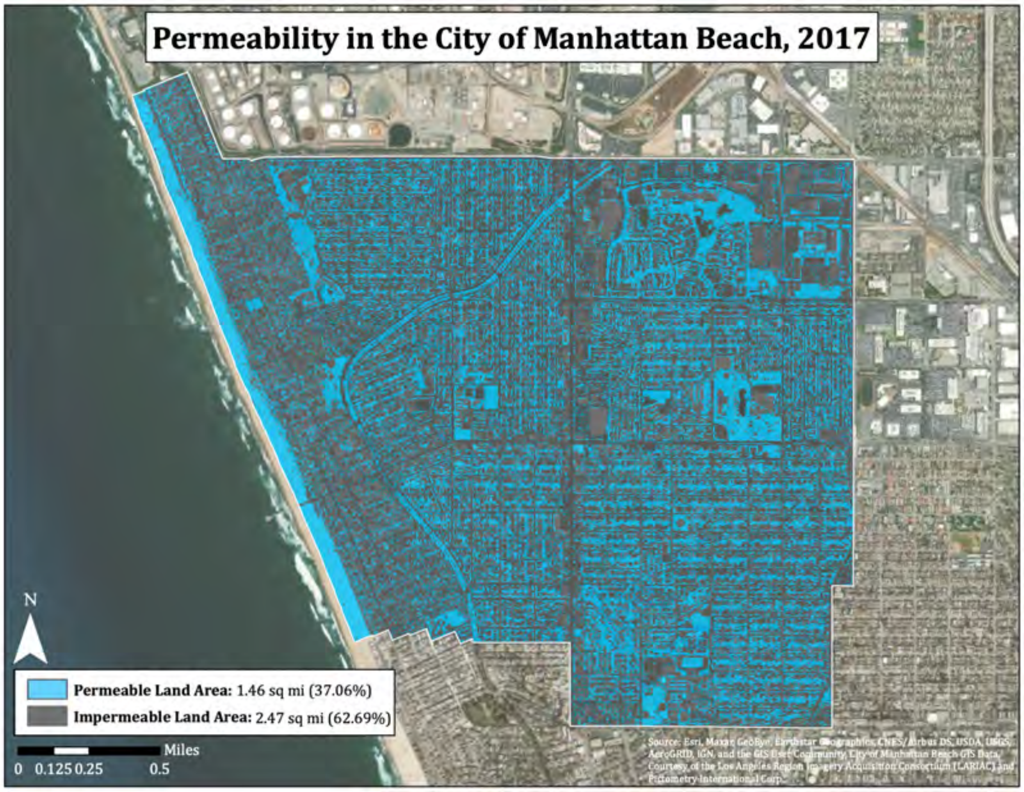
Figure 14. Permeability in the City of Santa Monica in 2017.



Similarly, *Figure 15* shows the permeable (vegetation, sand, water) and impermeable (buildings, roads) area in Manhattan Beach in 2017, derived from LARIAC 5 data through land classification. Permeable area represents 37.06% of Manhattan Beach, while impermeable area represents 62.69%.

From our 2017 land classification methodology, the City of Santa Monica (47.12% permeable) contains more permeable area than the City of Manhattan Beach (37.06% permeable).

Figure 15. Permeability in the City of Manhattan Beach in 2017.



Species Richness

Figure 16 shows that there is a very high variability across Santa Monica in species richness. Large swaths of the City have 0 observed unique species, while a handful have upwards of 30 observed unique species. However, Santa Monica has overall much higher rates of biodiversity compared to Manhattan Beach, as shown in *Figure 17*, where the largest amount of unique species observations in a single quadrant was just 12. The three biggest hot spots in Santa Monica are as follows: the intersection of Wilshire Boulevard and 20th Street, the intersection of Santa Monica Boulevard and Lincoln Boulevard, and unsurprisingly, the Santa Monica Pier. The latter two hotspots can likely be explained by the high amount of human foot traffic in this area, so there is a higher chance that someone who uses iNaturalist would pass through these areas and take photos. Santa Monica Boulevard / Lincoln Boulevard is near Santa Monica's main downtown district. The Santa Monica Pier is also a popular tourist destination, again increasing the chance of iNaturalist data points. The pier could also have higher species richness because it is a popular fishing spot, and there may be fishers wishing to identify their catches. This is supported when looking back at the data in the iNaturalist app as there are an abundance of fish observations on the pier. At first glance it is quite unclear why the area next to the interchange of Wilshire Boulevard and 20th Street has such great species richness. A majority of these observations are clustered in a single plot on a block of 18th Street. Upon looking back at iNaturalist, it appears that a bulk of these sightings were all made by one user, seemingly in their backyard. This alone shows the clear limitations in using iNaturalist and other community science platforms. While this map should certainly prove helpful to give a rough estimate of the species richness across Santa Monica, it is by no means a perfect representation of the real world.

When looking at the data from Manhattan Beach, it is clear that there are fewer species richness hot spots in the City than Santa Monica. A possible explanation is that Santa Monica is a much more popular tourist destination, and thus gets higher foot traffic. The Santa Monica Pier specifically is a very popular site to see in Los Angeles County (Law, 2021). Another explanation could just be the variability of iNaturalist usage — perhaps Manhattan Beach simply has less residents who regularly use the application.

Figure 16. Species Richness in Santa Monica (2015 - 2021).

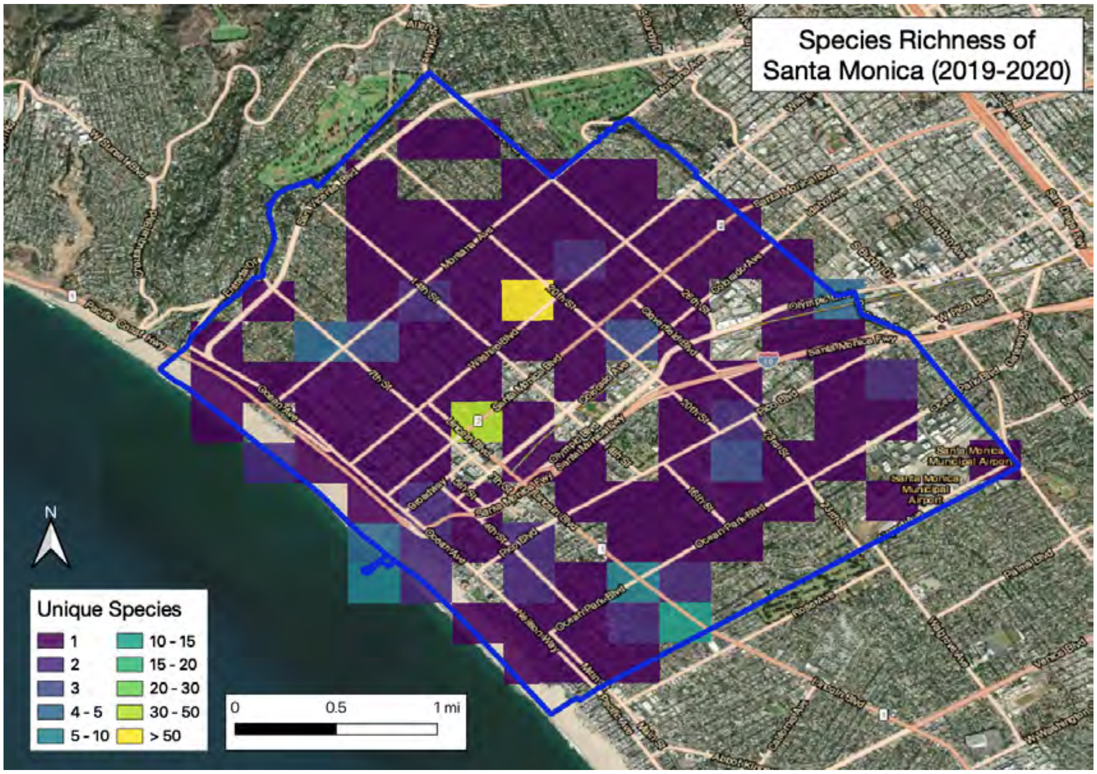
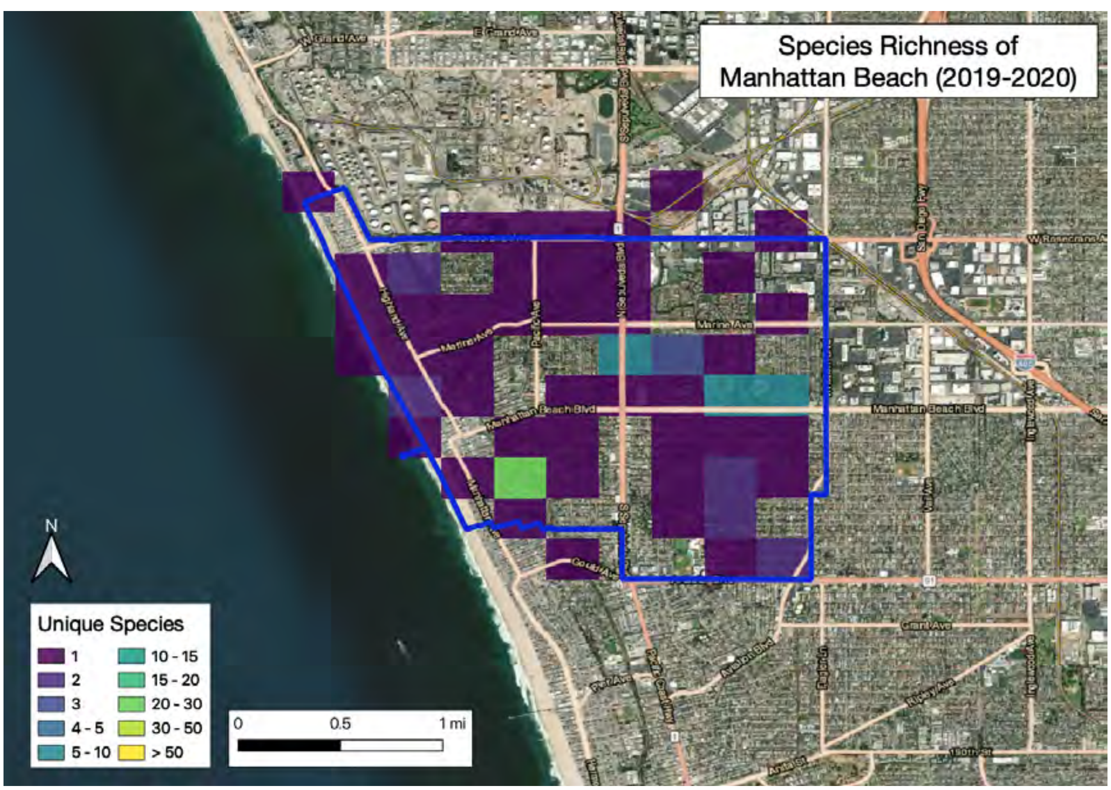


Figure 17. Species Richness in Manhattan Beach (2015 - 2021).



V. Discussion

Tree Canopy Cover (California Forest Observatory)

Barring extensive changes in land use and cover from development, we would not expect to see substantial changes in tree canopy coverage over a short period of time. Our analysis with California Forest Observatory data resulted in a Santa Monica citywide tree canopy coverage of 13.6% in 2017 and 13.4% in 2020. Overall, there is a less than 1% decrease in tree canopy cover over three years' time, pointing to a slightly negative but stable trend in tree cover change between 2017 and 2020. Similar values are seen in Manhattan Beach, with 13.9% tree canopy coverage in 2017 and 13.2% in 2020. The similarity between Santa Monica and Manhattan Beach is unsurprising given the similar environmental and urban characteristics of the two cities. Since the model employed by California Forest Observatory has a mean absolute error (MAE) of 7.0%, meaning that tree canopy coverage predictions are within 7.0% of observed values, the drops in canopy cover in both cities are likely too slight to be considered significant (Salo Sciences, Inc., 2020).

It is important to discuss our team's results for 2017 and 2020 as compared to the results of the previous urban tree canopy assessment, conducted for the year of 2014 by Dr. Qingfu Xiao and mentioned in the 2019 Santa Monica Sustainability Rights Report. Dr. Xiao's analysis resulted in a citywide tree canopy cover of 21.3% in 2005 and 20.5% in 2014. Xiao's 2014 tree canopy assessment utilized USDA NAIP 2005 imagery (1-meter resolution), Ortho-photographs 2014 3-band imagery, and LiDAR 2014 data (Xiao, 2018). The data source that we based our analysis on, California Forest Observatory, uses the same type of data: Sentinel-1 C-band radar sensors, Sentinel-2 multispectral sensors (10-meter resolution), and LiDAR from the USGS 3D Elevation Program (Salo Sciences, Inc., 2020).

The main difference in data that we noticed is that the data and results of Xiao's 2014 analysis is higher resolution (1-meter resolution) compared to the data and results of our 2017 and 2020 analysis (10-meter resolution), which could influence the final results. Xiao used a program called eCognition in his assessment, which is a feature extraction and change detection program for geospatial analysis (Trimble Geospatial, n.d.). California Forest Observatory uses deep learning models developed by Salo Sciences, Inc. These deep learning models use satellite imagery collected in the fall months between September and November for model training and prediction (Salo Sciences, Inc., 2020). Our team analyzed data from the summer months, and the fact that the California Forest Observatory deep learning models are based on fall canopy coverage may sway the final prediction and point to another key difference between the Xiao analysis and our team's analysis. Since the data and methodologies differ between Xiao's 2014 analysis and our 2017/2020 analysis, it is not appropriate to conduct a trend analysis. We were also not able to conduct a canopy cover study for 2014 using our methodology because the California Forest Observatory only offers tree canopy data for 2016-2020, so we did not have the opportunity to compare the results with Xiao's analysis.

However, our team did explore justifications for the potentially significant drop in tree canopy cover between 2014 and 2020. Jin Lee and colleagues (2017) explored the impact of housing redevelopment for single family homes such as housing additions on land cover change such as trees/shrubs. The average fraction of single family home square footage to lot size increased for all of Los Angeles County from 2000 to 2009, and the City of Santa Monica had the highest increase of all 20 cities considered. Building and hardscape cover increased about 16% while green cover decreased about 16%. Jin Lee and colleagues surmised that the percent of green cover reductions in the City of Santa Monica (~55% in 2000 to ~40% in 2009) resulted from housing development trends of remodeling homes to be larger.

It is also important to discuss our team's results for 2017 and 2020 as compared to other tree canopy cover assessments and peer-reviewed work. We will first consider how the City of Santa Monica ranks in the Singapore Index on Cities' Biodiversity, an internationally recognized self-assessment tool for cities to evaluate and track the progress of their biodiversity and ecosystem health (Convention on Biological Diversity, n.d.). Indicator 12 of the Singapore Index on Cities' Biodiversity is Climate Regulation: Carbon Storage and Cooling Effect of Vegetation, and this indicator is measured by the percentage of tree canopy cover in the city of interest. Tree canopy cover is essential for climate regulation, carbon sequestration, local cooling effects, air filtration, and biodiversity, which is why it is specifically measured in the Index. The ranking of this Indicator ranges from 0 points for less than 10.5% tree canopy cover to 4 points for greater than 59.7% tree canopy cover. Based on this ranking method and the results of our analysis, the City of Santa Monica would earn a score of 1 point for a 13.6% and 13.4% tree canopy cover in 2017 and 2020, respectively (Chan et al., 2014). From this evaluation scheme, Santa Monica would benefit from increasing its tree canopy coverage.

However, we recognize that the Singapore Index on Cities' Biodiversity is a general index that is not specific to local climatic and environmental conditions. Therefore, our team also compared our analysis to the Los Angeles County Tree Canopy Map Viewer developed by TreePeople and the Center for Urban Resilience (CURes) at Loyola Marymount University. This L.A. County tree canopy cover assessment is based on 2016 LiDAR data and imagery captured by the Los Angeles Region Imagery Acquisition Consortium (LARIAC) (Tree People & Loyola Marymount University Center for Urban Resilience, 2020). According to this Map Viewer, the average percentage of tree canopy cover for Los Angeles County is 18%, and the City of Santa Monica shows 21.11% tree canopy cover (TreePeople, 2020). It is clear that Santa Monica performs much better in this assessment as compared to our team's results (13.6% and 13.4% tree canopy cover in 2017 and 2020, respectively). The difference in results between our analysis and the Los Angeles County Tree Canopy Map Viewer is likely due to the different datasets and analysis methods used. It should be noted that the Los Angeles County Tree Canopy Map Viewer is based on 2016 data and it is unclear if the interactive map will be updated once new LARIAC data is available, so it may only be useful at this point in time.

Finally, our neighborhood-level analysis of tree canopy cover provides valuable information on the distribution of urban tree canopy throughout Santa Monica. As mentioned in the results section, the percent of tree canopy cover ranged from ~9% in the Pico Neighborhood Association area to ~22% in the North of Montana Association neighborhood, representing an uneven dispersal of tree canopy among various parts of the City. The North of Montana Association and Northeast Neighbors Association areas had the highest tree canopy coverage in 2017, and they also showed further increases in canopy cover from 2017 to 2020. Meanwhile, the Pico Neighborhood Association area had the lowest tree canopy coverage in 2017, and showed a further decrease in canopy cover from 2017 to 2020. Both of these trends point to a potentially diverging pattern of tree canopy coverage represented by a larger and growing gap between the most canopy-rich and canopy-poor areas of Santa Monica. One additional observation is that the northernmost and southernmost portions of the City have the highest proportions of tree canopy cover, and these areas largely correspond to residential neighborhoods. Meanwhile, the inner portions of the City characterized by more commercial land use have the lowest proportions of tree canopy cover. This trend mirrors the substantially lower biodiversity and lower soil permeability in these same areas. When comparing our team's neighborhood-level analysis to Xiao's 2014 urban tree canopy cover assessment and the Los Angeles County Tree Canopy Map Viewer, the percentage of tree canopy in each neighborhood differs, but overall trends and patterns are consistent across all analyses, including the high canopy coverage associated with the North of Montana Association and the low canopy coverage associated with the Pico Neighborhood Association area (Xiao, 2018; TreePeople, 2020).

The overall purpose of this analysis is to provide guidance and context for the City of Santa Monica to prioritize planting trees and promoting urban tree canopy health both citywide and in the areas that are lacking in coverage. Additionally, our replicable methodology and analyses provide an important starting point for the continuous tracking of urban tree canopy cover in Santa Monica over time.

Tree Canopy Cover (iTree)

The iTree Canopy analysis conducted for the City of Santa Monica, which resulted in 13.90% Tree/Shrub cover, provided results similar to those obtained through the California Forest Observatory analysis. The room for error with iTree data is relatively insignificant, with 1.09% for Tree/Shrub cover, when compared to the LiDAR technique. The accuracy of this random point sampling method depends on the interpreter's precision and the pixelation quality of a selected point. In areas where image quality is low, the accuracy of cover classification may be low. Impervious buildings make up the greatest coverage in the City of Santa Monica, at 32%, and impervious roads are a close second, at about 31%. This program is a cost-effective and efficient way to survey canopy coverage in a given area. Another benefit of using iTree is that we were able to calculate economic valuations of tree canopy coverage based on Los Angeles County's current economy. The most significant benefit is the amount of carbon sequestered annually in trees, at a value of $232,248. Other high valued benefits are the amount of ozone removed annually, at $71,082, and the amount of carbon stored in trees, at $4,588,124. The automatic calculations of these values by iTree allow for a better understanding of the environmental and economic benefits that tree canopy coverage provides for the City.

To improve the accuracy of tree canopy coverage values and their economic benefits, iTree should work to improve their satellite imagery quality, as their current imagery uses Google Earth. While the best approach for accuracy is field sampling, iTree is able to provide an accessible, cost-effective interface to quickly conduct tree canopy coverage surveys.

Permeability

Our 2014 permeability analysis using LARIAC 4 land cover data resulted in 38.78% permeable area and 61.22% impermeable area in the City of Santa Monica. As depicted in *Figure 10*, the northern and southern portions of the City have a higher density of permeable area than the inner portions of the City, which are largely impermeable. This observation mirrors the tree canopy cover and species richness results, with the central portions of the City exhibiting the most dense development, lowest canopy cover, and lowest species richness. LARIAC 4 land cover data is unavailable for Manhattan Beach, so we were not able to perform a comparative analysis between the two cities.

Our 2017 permeability analysis derived from LARIAC 5 imagery data through land classification resulted in 47.12% permeable area and 52.88% impermeable area in the City of Santa Monica. Similarly, our 2017 analysis for Manhattan Beach resulted in 37.06% permeable area and 62.69% impermeable area. According to the results of our land classification methodology, the City of Santa Monica (47.12% permeable) contains more permeable area than the City of Manhattan Beach (37.06% permeable).

Unfortunately, permeability results from 2014 and 2017 cannot be compared because distinct land classification methodologies were employed. The LARIAC 4 land cover data was classified into various land cover types through a complex data point extraction and classification method developed by GroundPoint Technologies, LLC but they did not conduct land classifications for LARIAC 5 data (Houston, 2016). Further, their classification protocol is not publicly available, so we could not replicate it. Thus, we conducted our own land classification for LARIAC 5 imagery. Additionally, we were not able to obtain LARIAC 4 imagery files in the same format as LARIAC 5, so we were unable to perform our land classification methods on LARIAC 4 imagery in order to compare our results to the LARIAC 4 land cover data obtained from Los Angeles County. Therefore, evaluating trends between the 2014 and 2017 permeability results is not recommended. Additionally, please note that our method of Maximum Likelihood Classification in ArcGIS is a rough land classification tool, and more advanced models such as that developed by GroundPoint Technologies, LLC to classify LARIAC 4 data are more accurate (Houston, 2016). Also note that both classification methods employ visual characteristics to classify ground features into different land cover classes, so it is possible that low impact development (LID) strategies such as permeable pavement or gravel were inappropriately classified as impermeable areas when they are in fact permeable areas. This is important to keep in mind if the City chooses to enact LID strategies in future development, as these strategies will likely need to be specially classified as permeable if an accurate percentage of permeable and impermeable area is to be determined.

Though we are not able to compare the results of our team's 2014 and 2017 analyses, it is important to discuss our team's results as compared to other permeability assessments and peer-reviewed work. Indicator 11 of the Singapore Index on Cities' Biodiversity is Regulation of Quantity of Water, which is measured by the proportion of permeable areas in the city of interest. Permeable land areas are important in order to reduce the flow of water in urbanized cities, clean polluted stormwater, promote water infiltration and the replenishment of groundwater, and increase cities' resilience in the face of climate change, which is expected to increase the variability in precipitation and therefore augment the risk of extreme weather conditions such as drought and flooding. The ranking for this indicator ranges from 0 points for less than 33.1% permeable land area to 4 points for over 75% permeable land area (Chan et al., 2014). The City of Santa Monica would therefore earn 1 point for 38.78% permeable land in 2014 and 2 points for 47.12% permeable land in 2017. According to the Singapore Index, Santa Monica is performing moderately well in terms of the amount of permeable land area provided.

Being mindful of the generalized nature of the Singapore Index on Cities' Biodiversity, our team also compared our assessment to the Los Angeles County Tree Canopy Map Viewer developed by TreePeople and the Center for Urban Resilience (CURes) at Loyola Marymount University, which uses Los Angeles Region Imagery Acquisition Consortium (LARIAC) 2016 imagery. This assessment breaks down the City of Santa Monica into the following land cover types: 27.44% buildings, 15.51% roads/railroads, 18.29% other paved surfaces, 21.11% tree canopy cover, 12.78% grass, and 4.86% bare soil. Adding together the impermeable (buildings, roads/railroads, other paved surfaces) and permeable (tree canopy cover, grass, bare soil) surfaces results in a total permeable area of 38.75% (TreePeople, 2020). This value is very close to our team's results for 2014 (38.78%), likely due to the fact that our team used LARIAC 4 imagery already classified by land cover type, so the methodologies were similar if not the same. However, the percentage obtained from the L.A. County Tree Canopy Map Viewer (38.75%) differs significantly from our team's results for 2017 (47.12%), which is likely due to the different datasets and analysis methods used. Unfortunately a Los Angeles County-average percent of permeable area was not provided by the L.A. County Tree Canopy Map Viewer, so we were unable to compare the City of Santa Monica to L.A. County as a whole, as we did for the tree canopy cover metric. It should be noted that the Los Angeles County Tree Canopy Map Viewer is based on 2016 data and it is unclear if the interactive map will be updated once new LARIAC data is available, so it may only be useful at this point in time.

Species Richness

We recommend collecting additional data to evaluate biodiversity in the City of Santa Monica. The species richness map we created based on research-grade data from iNaturalist shows a lack of data on the North East, North West, and South West edges of the city, as well as in the center between Pico, Santa Monica Blvd, 14th Street and Cloverfield Blvd. Further, the area with the highest number of unique species results from a single, avid iNaturalist user. This epitomizes some of the issues inherent in citizen science data (Conrad 2011). We attempted to correct for spatial bias by looking at species richness instead of pure abundance. Because iNaturalist relies on citizen observations, there is no way to distinguish specific individuals within a species. Therefore, it is possible that our iNaturalist data includes multiple observations of the same individual. By only looking at species richness, these observations are all counted as one, if within a certain bound of each other. Even given the limitations of our map, however, some of the results are corroborated by our other analyses. The species richness map shows lower species richness in the industrialized areas of the City, namely the Pico district. These areas of low species richness also have low canopy cover and low permeability. One possible explanation is that there are fewer species in the built-up areas of the City. Yet, it is also possible that low species richness in the industrialized areas of the City may be a result of the simple fact that those areas are not used for leisure activities, so fewer people record species in those areas.

The underlying biodiversity data for the City of Santa Monica could be improved by encouraging a systematic approach to iNaturalist data collection, or the City could complete its own biodiversity study. If the City wanted to encourage an iNaturalist data collection campaign, they might work with the iNaturalist app in order to build a marketing strategy that encourages public engagement. To get more accurate biodiversity data through the iNaturalist app, the City of Santa Monica could plot a random sample of geographic locations across the City and request users to take a photo of any species they see (even if it is not a charismatic one) at a specific plot. In order for this to be an effective methodology, increased public engagement with iNaturalist would be necessary.

VI. Conclusion

The City of Santa Monica reports biannually on the ecosystem health metrics of their city. Our team assisted them by evaluating tree canopy cover, ecosystem services related to canopy cover, permeability, and species richness. In terms of tree canopy coverage, our analysis using California Forest Observatory data showed a citywide tree canopy coverage of 13.6% in 2017 and 13.4% in 2020, representing a slight, potentially insignificant decrease that may be explained by development and property owner removal of trees. For permeable surfaces, our analysis of 2014 LARIAC 4 land cover data reveal permeable area represents 38.78% of the City, while impermeable area represents 61.22% of the City. Our classification analysis of 2017 LARIAC 5 data reveal permeable area represents 47.12% of the City, while impermeable area represents 52.88% of the City.

One important takeaway with regards to our team's tree canopy cover and permeability analysis is that the data sources and methodologies chosen for analysis *significantly* impact the final results. The results obtained through our California Forest Observatory tree canopy cover analysis, iTree canopy cover analysis, and 2017 LARIAC 5 land classification analysis resulted in significantly different estimates as those obtained through Xiao's 2014 urban tree canopy assessment, GroundPoint Technologies, LLC's professionally classified LARIAC 4 data, and the Los Angeles County Tree Canopy Map Viewer.

In order to conduct trend analyses for different ecosystem health metrics, it is therefore essential that the City of Santa Monica chooses consistent data sources and methodologies that are replicable and comparable over time. For example, our group obtained classified 2014 LARIAC data from Los Angeles County and discovered classified 2016 LARIAC data through TreePeople's Los Angeles County Tree Canopy Map Viewer, and both of these sources provide tree canopy cover and permeability estimates. However, it is unclear if future iterations of LARIAC data will be classified and documented in a similar manner. It may therefore be in the best interest of the City to advocate for the ongoing classification of LARIAC data into land cover types in order to ensure consistent methodologies over time.

In order to better evaluate the state of biodiversity in Santa Monica, the city needs more data and higher quality data. Biodiversity data were quite limited and currently rely heavily on citizen science. In order to improve the underlying data the city could set up a sampling design throughout the city while also promoting an event similar to the Biodiversity Blitz previously held by the city. In order to undertake this, the city must identify a suitable sampling strategy that is repeatable through time and provide explicit and simple directions for anyone interested in participating in data collection such as going to a set location, looking north, and taking a photo of the first living species you see. This would allow the city to have access to a revolving door of continually updated data across the city and this data could then be randomly selected using a reproducible sampling method in order to draw meaningful conclusions about the state of biodiversity in the city.

In summary, our team's analysis pointed to a potential decrease in urban tree canopy coverage over the last decade, likely due to increased development; a pattern of species richness that is higher in parks and near the ocean; and parallels between areas of high/low permeability and areas of high/low tree canopy cover and species richness. Upon deeper analysis, our primary recommendation is that the City advocates for and chooses data sources that are consistent over time. Specifically, the City should advocate for the ongoing classification of LARIAC data so that the methodology for calculating permeability and land use remains consistent, and also encourage the systematic collection of biodiversity data, such as through a citizen science campaign.

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VIII. Appendix A: Protocol Step-by-Step Methodology

Species Richness Methodology (iNaturalist)

1. Download data from gbif. Import as iNaturalist_Data.shp. Import municipality/city bounds. Clip data accordingly (output: iNaturalist_clip.shp)

2. Reproject species observations (Vector > Data management tools > Reproject layer) |Input: iNaturalist_clip.shp |Reproject to: EPSG:6423 |Output: iNaturalist_clip.shp6423.shp

3. Create a fishnet grid. (Vector > Research Tools > Create Grid) |Input: iNaturalist_clip.shp6423.shp |Grid type: polygon Extent: inatclip6423.shp |Horizontal and vertical spacing: 30m |Grid CRS: EPSG:6423 |Output: SMGrid.shp

4. Spatial join between species observations and grid. (Processing toolbox > Join attributes by location) |Input layer: inatclip6423.shp |Join layer: SMGrid.shp |Geometric predicate: Intersects |Fields to add: All |Join type: One to one |Output layer: SMJoin.shp

5. Count species per grid cell. (Processing toolbox > Statistics by category) |Input: SMJoin.shp |Field to calculate statistics on: verbatimScientificName |Field with categories: id |Output: SpeciesCount.csv

6. Convert species count field to numeric in SpeciesCount.csv Right click on SpeciesCount.csv and open attribute table. Open field calculator and create a new field named 'id_num', set it equal to 'id' but make sure it's a whole number of length 10.

7. Merge species count data back into SMJoin.shp (Processing toolbox > Join attributes by field value) |Input layer: SMJoin.shp |Table field: id |Input layer 2: SpeciesCount.csv |Table field 2: id_num |Layer 2 fields to copy: count |Join type: one to one |Output: SMSpeciesCount.shp

8. Convert species count field to numeric in SMSpeciesCount.shp Right click on SMSpeciesCount.shp and open attribute table. Open field calculator and create a new field named 'count_num', set it equal to 'count' but make sure it's a whole number of length 10.

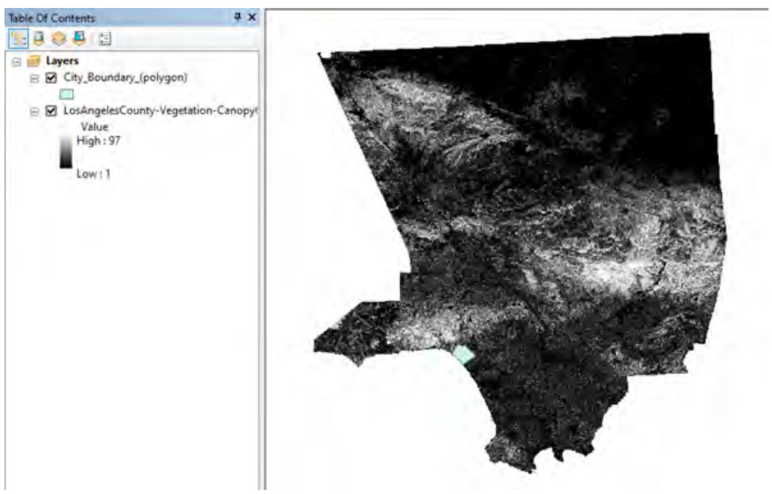
9. Rasterize species count data. (Raster > Conversion > Rasterize) |Input: SMSpeciesCount.shp |Field for burn in value: count_num |A fixed value to burn: Not set |Output raster size: pixels |Horizontal and vertical resolution: 30m (or other desired resolution) |Output extent: SMSpeciesCount.shp |No data: -9999 |Output: SMSpeciesCount.tif

Citywide Tree Canopy Cover Methodology (California Forest Observatory)

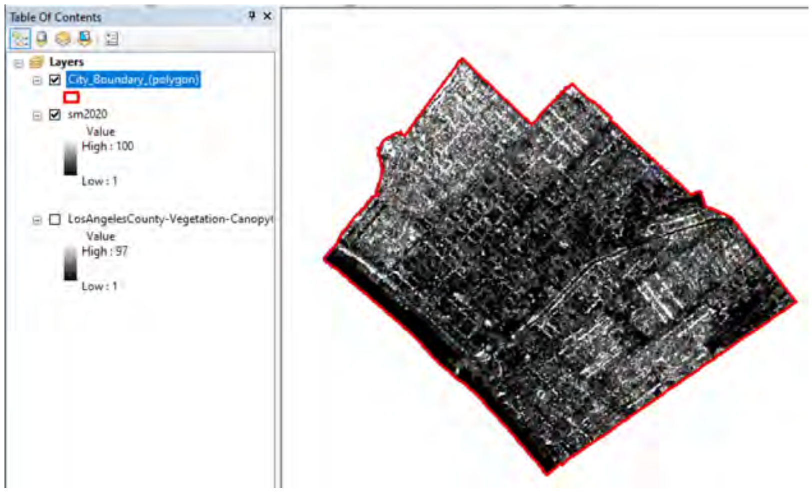
Download Tree Canopy Cover dataset from California Forest Observatory

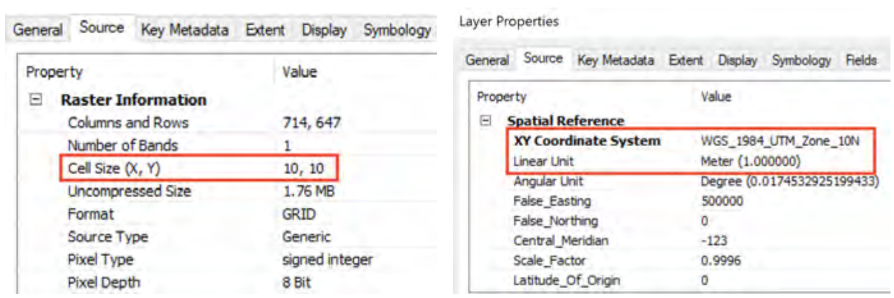
1. Create an account.
2. Click on the Download button in the upper left ribbon.
3. Download By: Counties, and then click on LA County.
4. Click on the Canopy Cover dataset.
5. Click Download (will download a .tif raster file).

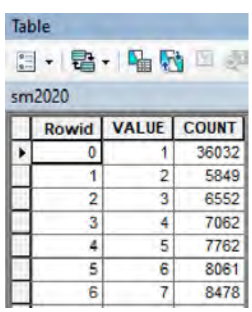
Analyze in ArcGIS

1. Open the tree canopy cover .tif raster file in ArcGIS.
2. Open the City of Santa Monica polygon boundary shapefile (downloaded from Santa Monica GIS Data portal).
    a. It will look like this:
    b. 

3. Extract the .tif file to SM City Boundaries:
    a. ArcToolbox - Spatial Analyst Tools - Extraction - Extract by Mask
        i. Input Raster: Choose the canopy cover .tif raster file.
        ii. Input Raster or Feature Mask Data: Choose the SM boundary shapefile.
        iii. Output Raster: Choose an output folder and name the output raster.
        iv. Click OK.
    b. If you zoom to the new extracted SM raster, it looks like this:

c. 

4. Calculate area of tree canopy cover in SM:
    a. [The dataset](#) is 10m resolution, so each pixel is 10m x 10m = 100 square meters. Right click on the tree canopy cover raster, click on Properties, and go to the Source tab to confirm the resolution and linear unit.
        i. 

    b. Each 100 sq m pixel is assigned a value from 0-100, representing the percentage of that pixel that is covered by tree canopy.
    c. Open Attribute Table of clipped SM raster layer:
        i. VALUE is the percentage tree canopy cover from 0-100.
        ii. COUNT is the number of pixels with each corresponding percentage value.
        iii. 

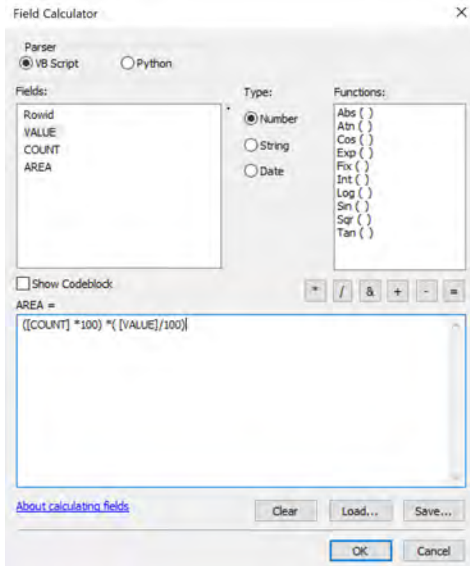
Table

sm2020

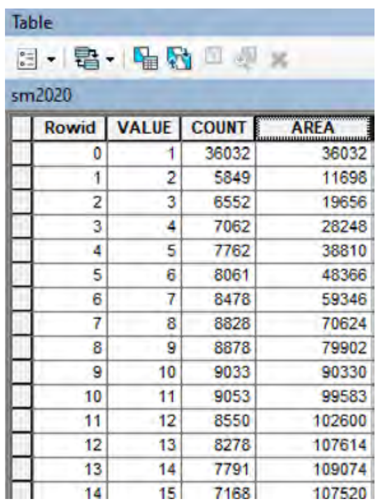
Rowid	VALUE	COUNT
0	1	36032
1	2	5849
2	3	6552
3	4	7062
4	5	7762
5	6	8061
6	7	8478

    d. Calculate area covered by tree canopy:
        i. In the Attribute Table, click on Table Options (upper left icon) - Add Field
            1. Name: Area - Type: Long Integer - Precision: 10 - Click OK
        ii. Right Click on the new Area column - Field Calculator - Yes

iii. Add this calculation: ([COUNT]*100) * ([VALUE]/100)

1. 

iv. Updated table with new Area field will look like this:

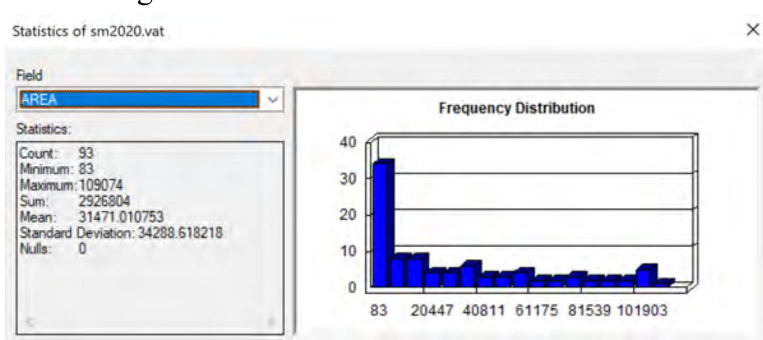
1. 

Table

sm2020

Rowid	VALUE	COUNT	AREA
0	1	36032	36032
1	2	5849	11698
2	3	6552	19656
3	4	7062	28248
4	5	7762	38810
5	6	8061	48366
6	7	8478	59346
7	8	8828	70624
8	9	8878	79902
9	10	9033	90330
10	11	9053	99583
11	12	8550	102600
12	13	8278	107614
13	14	7791	109074
14	15	7168	107520

v. Find total area: Right click on Area column - Statistics

1. 

2. **Sum** is the total area covered by tree canopy in square meters (2,926,804 square meters)

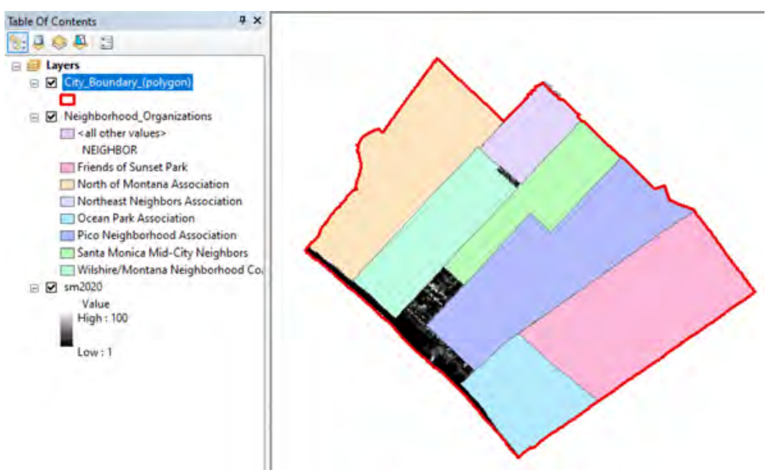
vi. Calculate the percentage of tree canopy coverage by dividing the area covered by tree canopy by the total area of the City of Santa Monica.

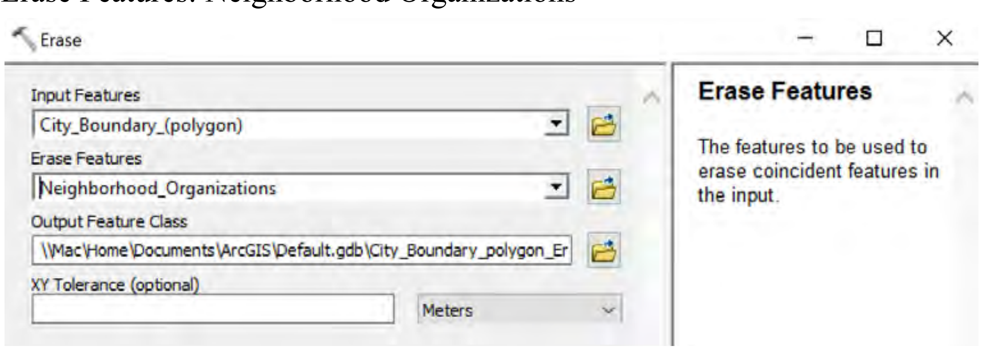
Neighborhood Tree Canopy Cover Methodology (California Forest Observatory)

Prepare data

1. If the California Forest Observatory tree canopy cover data has not already been downloaded and extracted to the correct extent, refer to the "Citywide Tree Canopy Cover Methodology (California Forest Observatory)" on page 39 and perform the first few steps, up to number 3 of the "Analyze in ArcGIS" section.

Analyze in ArcGIS

1. In ArcGIS, open the tree canopy cover raster (extracted to Santa Monica city boundaries) and the City of Santa Monica neighborhood shapefile (downloaded from Santa Monica GIS Data portal).
    a. It will look like this:
    b. 

2. Create a polygon for the portions of Santa Monica that are not assigned neighborhoods. ArcToolbox - Analysis Tools - Overlay - Erase.
    a. Input Features: City Boundary (polygon)
    b. Erase Features: Neighborhood Organizations
    c. 

d. Output:

3. Create separate polygons for each neighborhood. Use the Select tool and click on one neighborhood.

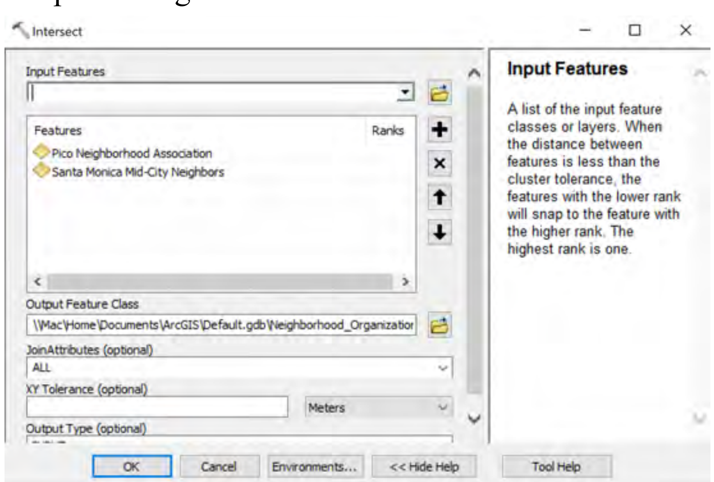
a.

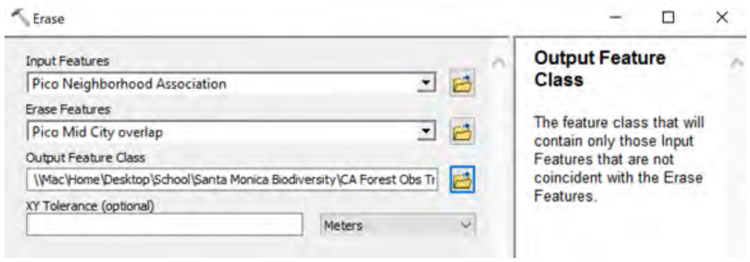
b. Right click on the Neighborhood Organizations layer - Selection - Create Layer from Selected Features. Rename to match the neighborhood name. Repeat for all neighborhoods.

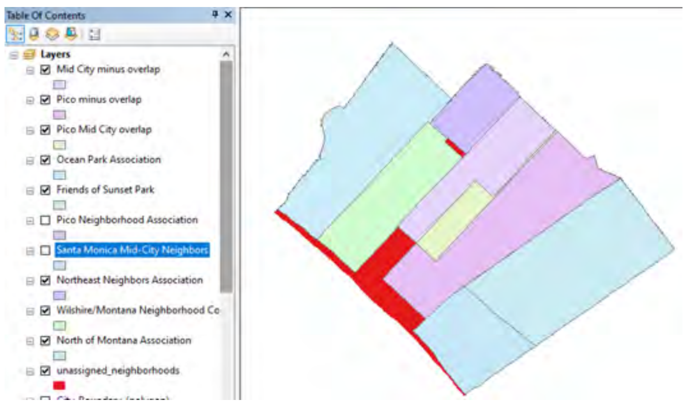
4. Pico Neighborhood Association and Santa Monica Mid-City Neighbors have an overlap. Create a separate polygon for this overlapping area so tree canopy cover is not double counted.

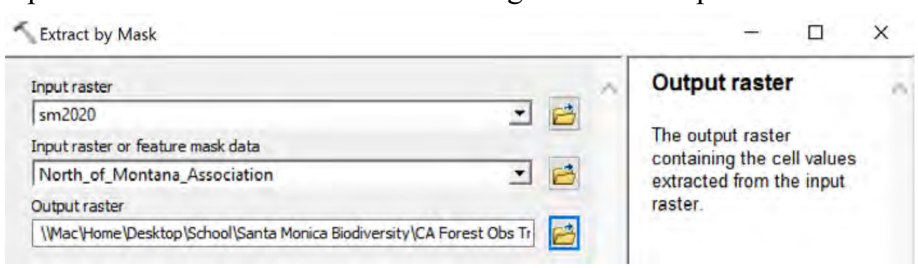
a. Geoprocessing - Intersect. Choose Pico and Santa Monica Mid-City.

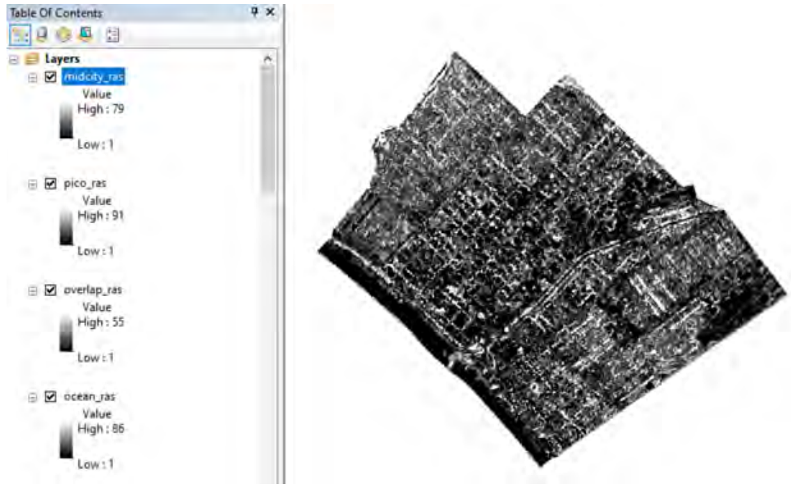
b.



5. Erase the overlap from Pico Neighborhood Association and Santa Monica Mid-City Neighbors. ArcToolbox - Analysis Tools - Overlay - Erase.
    a. Input Features: Pico
    b. Erase Features: Overlap
    c. Repeat for Santa Monica Mid-City
    d. 

    e. 

6. Extract the tree canopy cover raster to each neighborhood boundary.
    a. ArcToolbox - Spatial Analyst Tools - Extraction - Extract by Mask
        i. Input Raster: SM canopy cover raster
        ii. Input Raster or Feature Mask Data: Neighborhood shapefile
        iii. 

iv. 

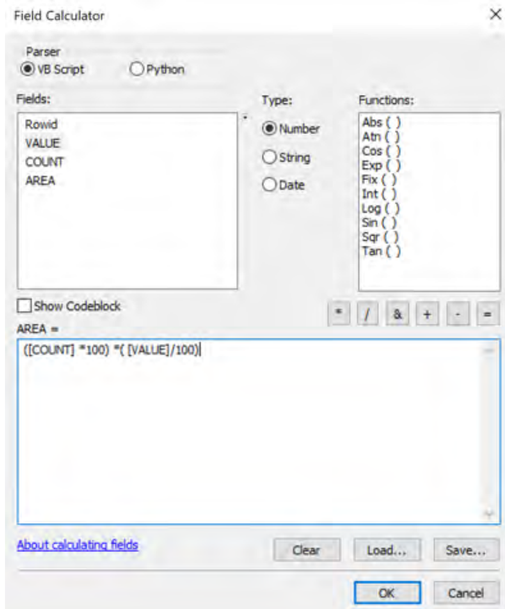
7. Calculate area of tree canopy cover in each neighborhood:
    a. [The dataset]() is 10m resolution, so each pixel is 10m x 10m = 100 square meters. Each 100 sq m pixel is assigned a value from 0-100, representing the percentage of that pixel that is covered by tree canopy.
    b. Open Attribute Table of clipped neighborhood raster layer:
        i. VALUE is the percentage tree canopy cover from 0-100
        ii. COUNT is the number of pixels with each corresponding percentage value
        iii.

Table

midcity_ras

Rowid	VALUE	COUNT
0	1	3411
1	2	782
2	3	880
3	4	906
4	5	1007
5	6	1044
6	7	1104

    c. Calculate area covered by tree canopy:
        i. In Attribute Table, click on Table Options (upper left icon) - Add Field
            1. Name: Area - Type: Long Integer - Precision: 10 - Click OK
        ii. Right Click on the new Area column - Field Calculator - Yes
        iii. Add this calculation: ([COUNT]*100) * ([VALUE]/100)

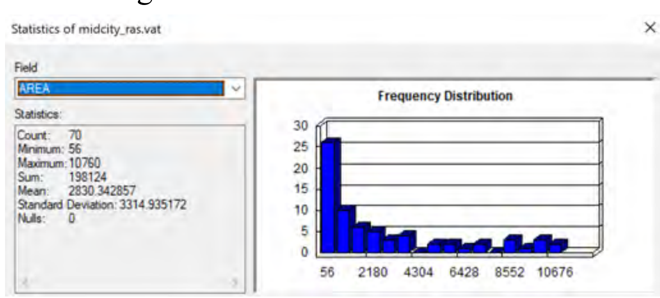
1. 

iv. Updated table with new Area field will look like this:

1. midcity_ras

Rowid	VALUE	COUNT	AREA
0	1	3411	3411
1	2	782	1564
2	3	880	2640
3	4	906	3624
4	5	1007	5035
5	6	1044	6264
6	7	1104	7728
7	8	1106	8848
8	9	1159	10431
9	10	1076	10760
10	11	938	10318
11	12	890	10680
12	13	799	10387

v. Find total area: Right click on Area column - Statistics

1. 

2. **Sum** is the total area covered by tree canopy in square meters

d. Calculate percentage of tree canopy coverage:

i. Convert tree canopy from square meters to square km

ii. Total area of Santa Monica neighborhoods from Xiao's 2014 analysis:

Table 1. List of Neighborhoods

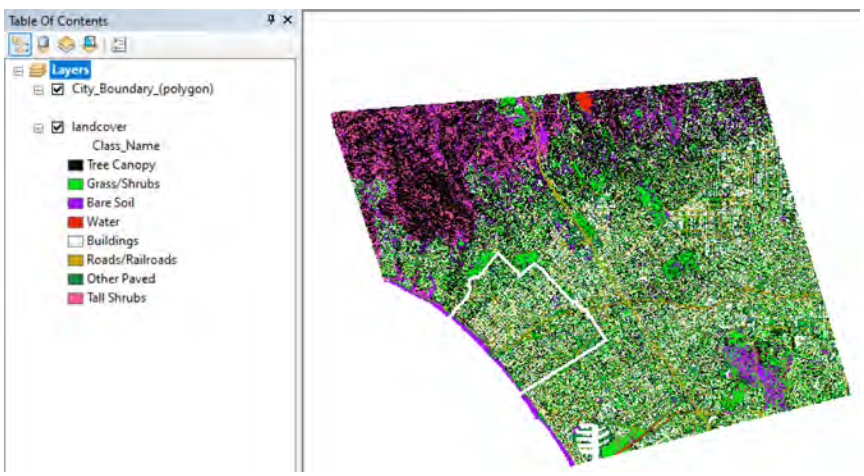
iii.

Neighborhood Name	Area (km^2)
Friends of Sunset Park	4.82
North of Montana Association	3.91
Northeast Neighbors Association	1.16
Ocean Park Association	1.94
Pico Neighborhood Association	4.45
Santa Monica Mid-City Neighbors	1.90
Wilshire/Montana Neighborhood Coalition	2.43
Overlap Area	0.58
Unassigned Neighborhood Area	0.55

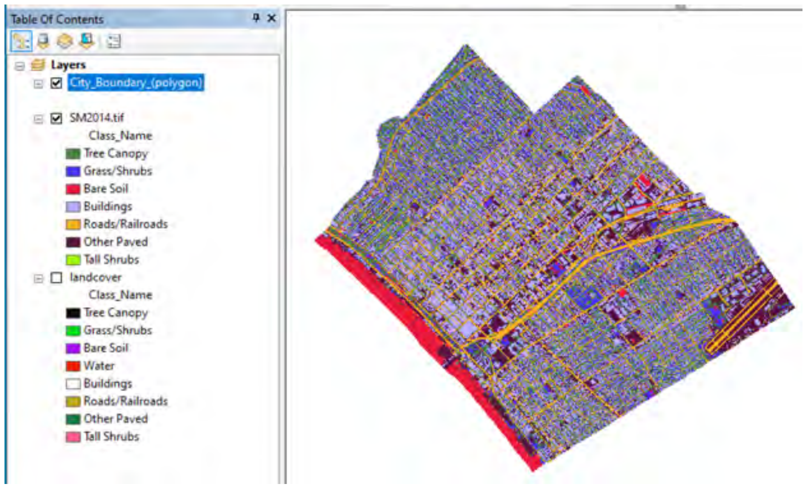
iv. Divide the area covered by tree canopy by the total area of each neighborhood to obtain the percent of each neighborhood covered by tree canopy.

Land Cover/Permeability Methodology (LARIAC 4)

1. Open the LA County 2014 LARIAC 4 land cover raster in ArcGIS. Also open the City of Santa Monica polygon shapefile.

a. 

2. Extract the LA County raster to City of Santa Monica boundaries.
    a. ArcToolbox - Spatial Analyst Tools - Extraction - Extract by Mask
    b. Input Raster: land cover
    c. Input raster or feature mask data: City of SM boundary
    d. Output raster: Name file and choose location.

e. 

3. Calculate area.
   a. Open the attribute table of the classified raster. The count tells you how many pixels are in each classified land cover type.
   b.

SM2014.tif

OID	Value	Count	Class_Name
0	1	89034002	Tree Canopy
1	2	53901263	Grass/Shrubs
2	3	20501553	Bare Soil
3	5	115712619	Buildings
4	6	65403858	Roads/Railroads
5	7	77120982	Other Paved
6	8	9958	Tall Shrubs

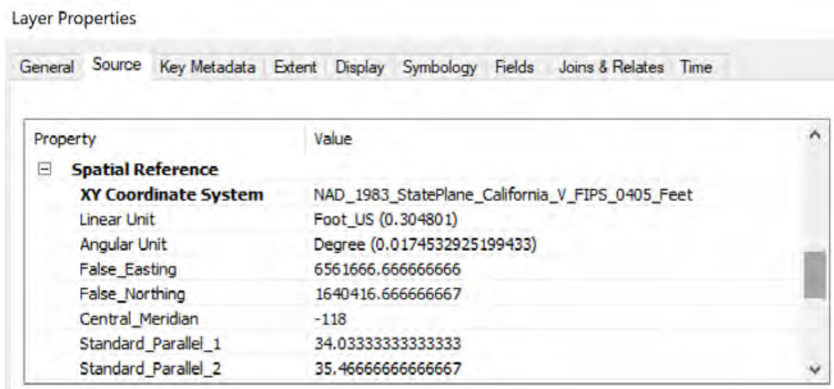
   c. Right click on the extracted SM raster in the Table of Contents, click on Properties, and go to the Source tab.
      i. The cell size (0.75, 0.75) tells you the size of each pixel in the raster.
      ii.

Layer Properties

General | Source | Key Metadata | Extent | Display | Symbology | Fields | Joins & Relates | Time

Property	Value
Raster Information	
Columns and Rows	30084, 27059
Number of Bands	1
Cell Size (X, Y)	0.75, 0.75
Uncompressed Size	388.17 MB
Format	TIFF
Source Type	Generic
Pixel Type	unsigned integer
Pixel Depth	4 Bit

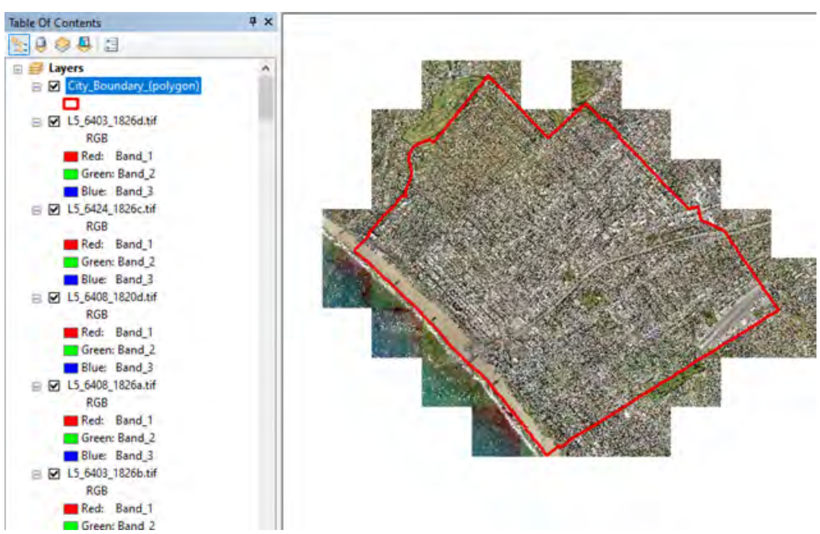
      iii. Scroll down in that same window to confirm the coordinate system. Since the coordinate system is NAD 1983 CA State Plane and the linear unit is feet, the cell size of (0.75, 0.75) would correspond to 0.75*12 inches = 9 inches x 9 inches.

iv. 

d. So, each pixel is 9 inches by 9 inches = 81 sq inches.
e. Calculate the area associated with each land cover type by multiplying the number of pixels in a specific class by the area of each pixel (81 sq in).
f. Add the areas of tree canopy + grass/shrubs + bare soil + tall shrubs to estimate the permeable area in the City, and add the areas of buildings + roads/railroads + other paved to estimate the impermeable areas of the City.
g. Calculate the percentage of permeable and impermeable area by dividing the area of permeable and impermeable surfaces by the total area of the City.

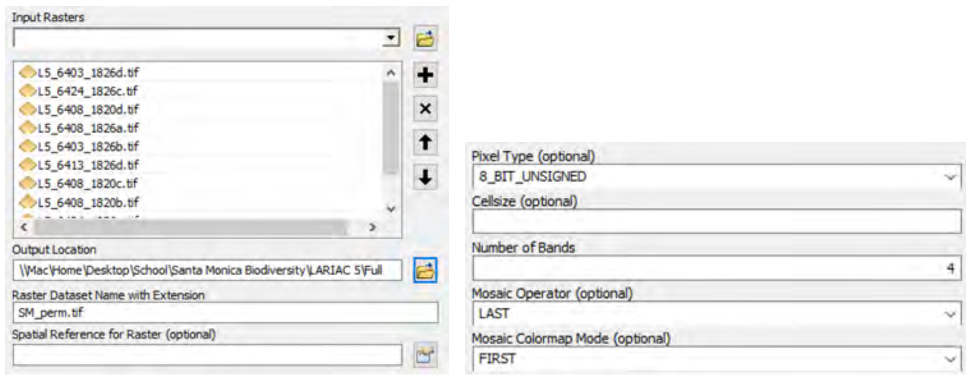
Permeability Methodology (LARIAC 5)

1. Download the 2017 LARIAC 5 imagery tiles covering the entire extent of the City of Santa Monica. Our team downloaded the files through UCLA's Data Science Center.
2. Open all .tif image files in ArcMap. Also add a City of Santa Monica polygon shapefile to make sure the full extent of Santa Monica is covered.

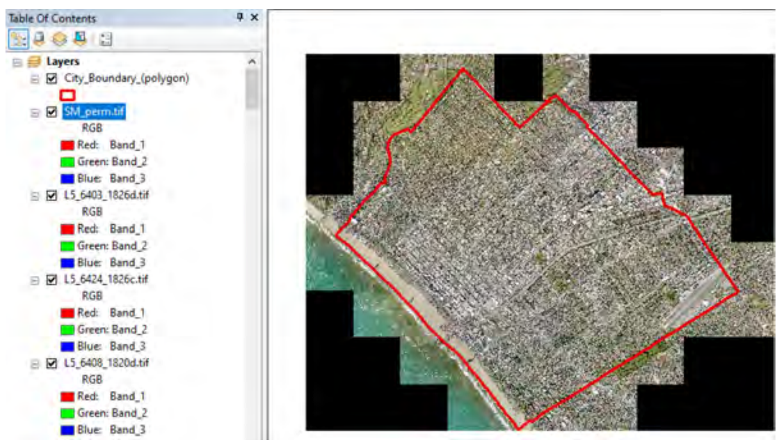
a. 

3. Merge all separate rasters into one new output raster. Go to Arc Toolbox - Data Management Tools - Raster - Raster Dataset - Mosaic to New Raster

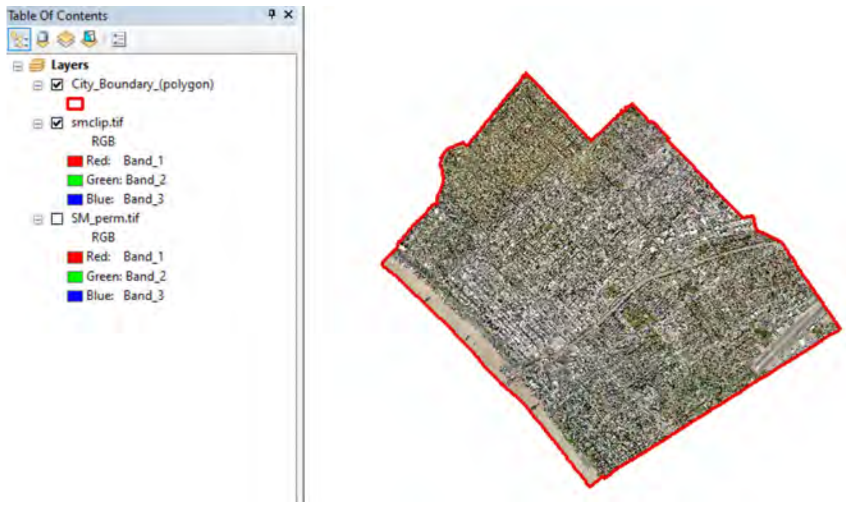
a. Input Rasters: input all the raster files here.
b. Output Location: Choose an output location.
c. Raster Dataset Name with Extension: file_name.tif. Make sure to add .tif at the end.
d. Number of Bands: 4.
e. Mosaic to New Raster tool inputs:



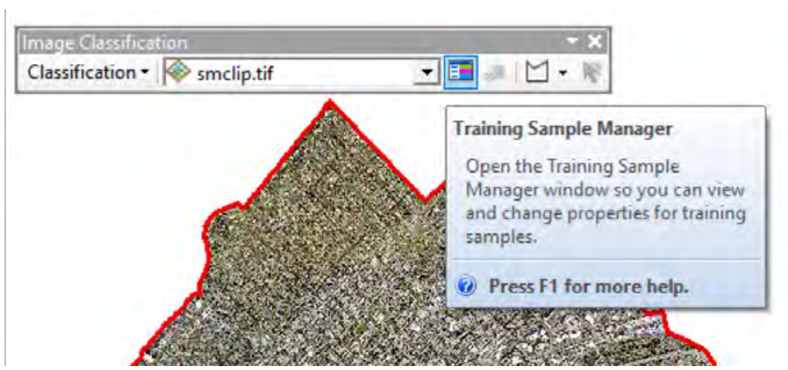
f. Output raster:



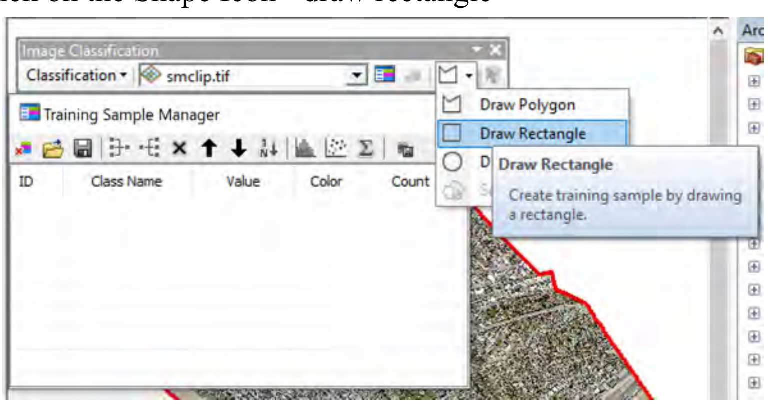
4. Extract the output raster to the City of Santa Monica boundary. Go to Arc Toolbox - Spatial Analyst Tools - Extraction - Extract by Mask.
   a. Input raster: The output raster you just created.
   b. Input raster or feature mask data: SM polygon shapefile.
   c. Output raster: Name file and choose location.

d. 

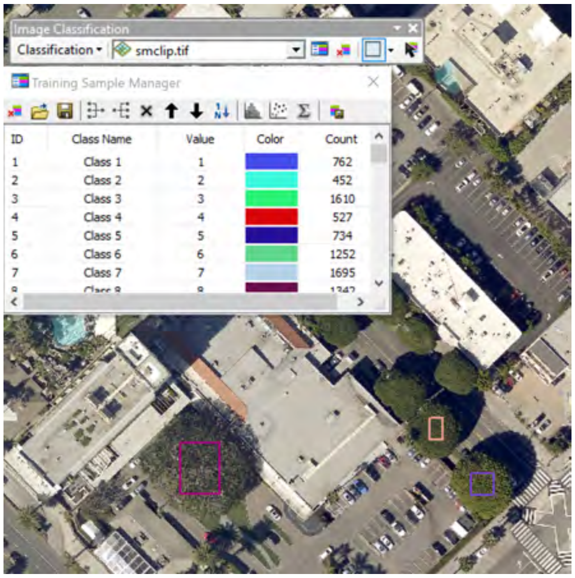
5. Go to Customize - Extensions - Make sure "“Spatial Analyst” is checked.
6. Go to Customize - Toolbars - Image Classification.
7. In the Image Classification bar, make sure the new complete output raster is selected from the drop-down menu. Click on the Training Sample Manager icon.

a. 

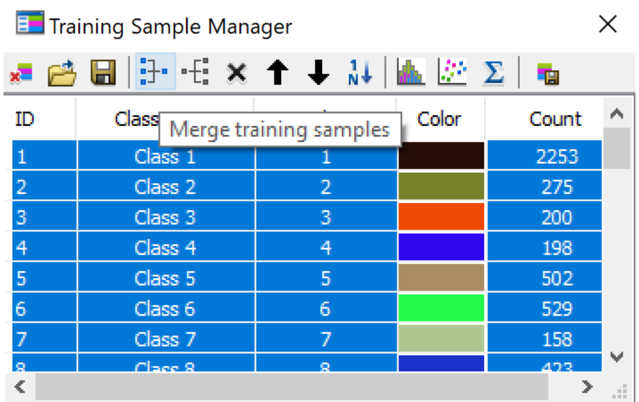
8. Then click on the Shape Icon - draw rectangle

a. 

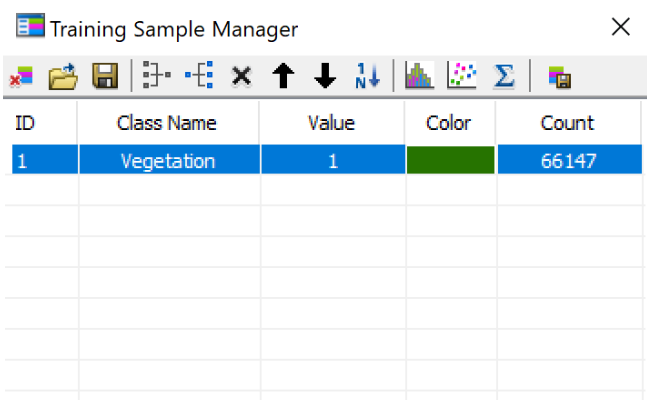
9. Draw rectangles within one land cover type of interest (vegetation, sand, urban, water, etc.). The more samples you take, the more accurate it is. This example is for vegetation.

a. 

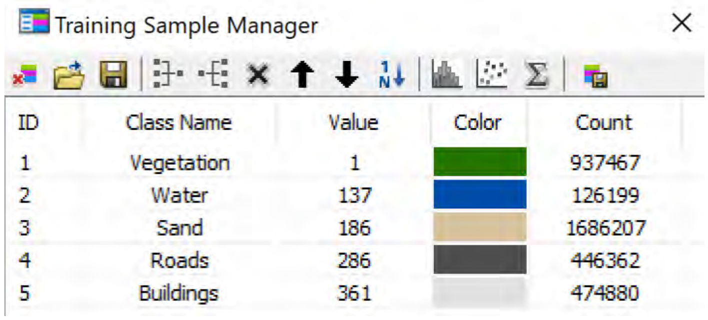
b. Then select all the samples for that land cover type - Merge all Training Samples.

c. 

d. Then change the color and name to something descriptive.

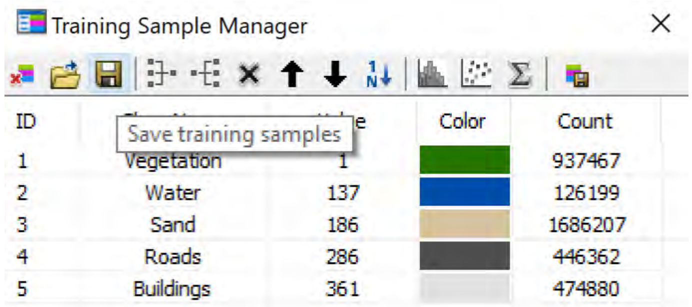
e. 

10. Repeat for other land cover types.



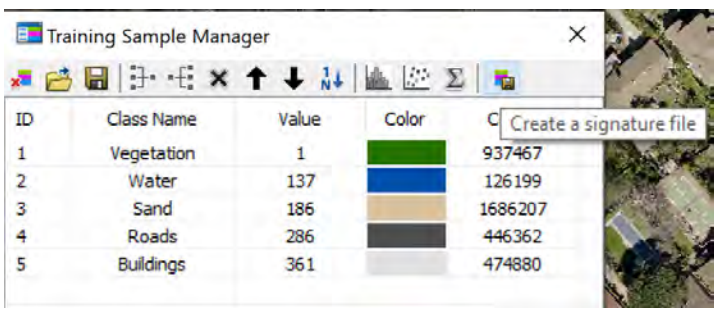
a.

11. Save samples as a shapefile.



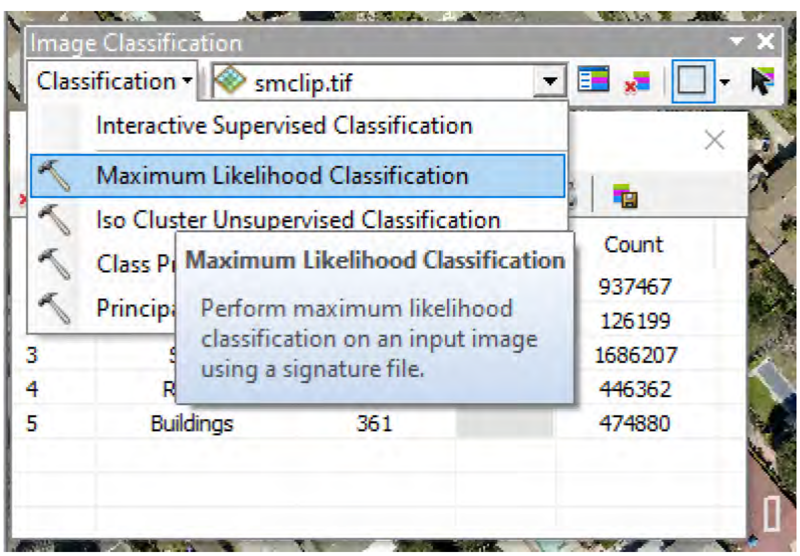
a.

12. Create a signature file (.gsg)



a.

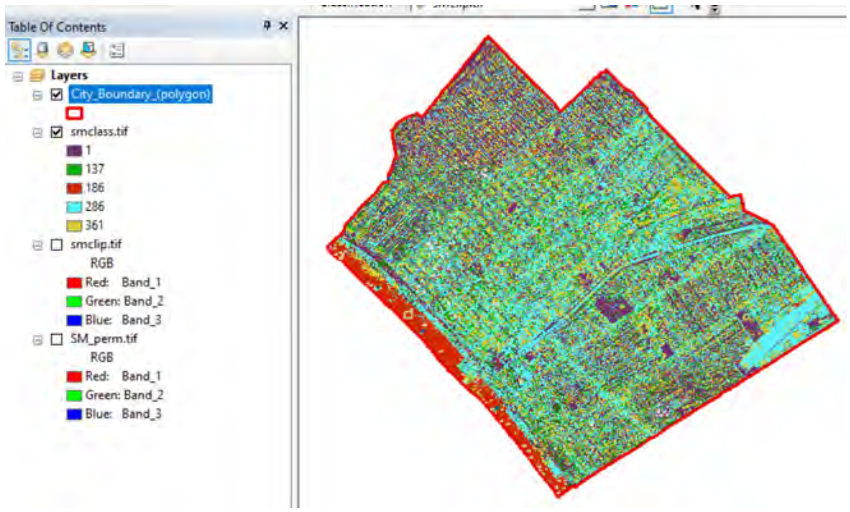
13. Then click on Classification - Maximum Likelihood Classification



a.

b. Input raster band: original raster we've been working with.

c. Input signature file: signature file we just saved.
d. Output raster file: name the new output file (put .tif at the end of the file name).
e. Everything else in the window stays the same.
f. Here's the output:

i. 

14. Change the colors and labels.

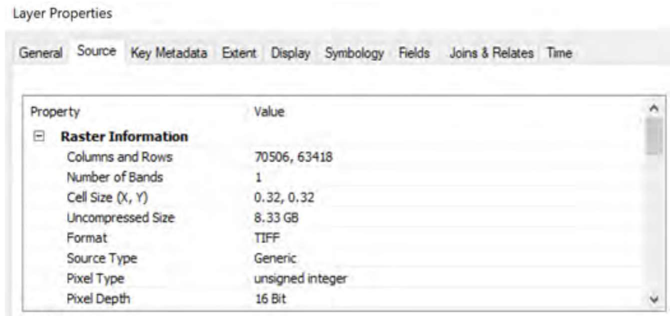
a. 

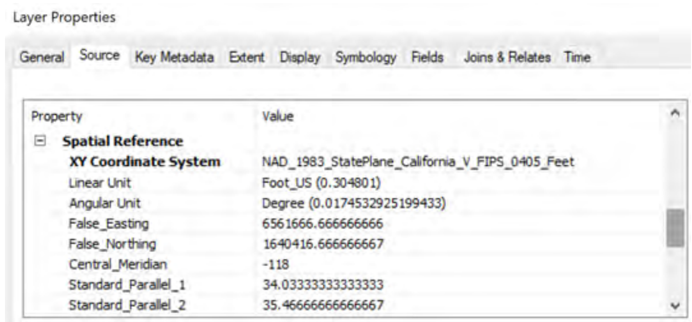
15. Calculate Area

a. Open the attribute table of the classified raster. The count tells you how many pixels are in each classified land cover type.

i. smclass.tif

OID	Value	Count
0	1	595274754
1	137	323824864
2	186	172780665
3	286	719016929
4	361	505657927

b. Right click on the classified raster in the Table of Contents, click on Properties, and go to the Source tab.
    i. The cell size (0.32, 0.32) tells you the size of each pixel in the raster.
    ii. 

    iii. Scroll down in that same window to confirm the coordinate system. Since the coordinate system is NAD 1983 CA State Plane and the linear unit is feet, the cell size of (0.32, 0.32) would correspond to 0.32*12 inches = 3.84 inches x 3.84 inches.
    iv. 

c. So, each pixel is 3.84 inches by 3.84 inches = 14.7456 sq inches.
d. Calculate the area associated with each land cover type by multiplying the number of pixels in a specific class by the area of each pixel (14.7 sq in).
e. Add the areas of vegetation + sand + water to estimate the permeable area in the City, and add the areas of buildings + roads to estimate the impermeable areas of the City.
f. Calculate the percentage of permeable and impermeable area by dividing the area of permeable and impermeable surfaces by the total area of the City.

IX. Appendix B: Key Figures Slide Deck

Key Figures Slide Deck:
https://docs.google.com/presentation/d/1PR-SIrjd7ljgXkh-99sfe-yUKZH0Nw-4FTxqZFzBhkI/edit?usp=sharing