

# A Report on Honolulu's Existing and Possible Tree Canopy



## Why is Tree Canopy Important?

Tree canopy (TC) is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above. Tree canopy provides many benefits to communities by improving water quality, saving energy, lowering ambient temperatures, reducing air pollution, enhancing property values, providing wildlife habitat, facilitating social and educational opportunities, and providing aesthetic benefits. Establishing a tree canopy goal is crucial for communities seeking to improve their green infrastructure. A tree canopy assessment is the first step in this goal-setting process, providing estimates for the amount of tree canopy currently present in an area as well as the amount of tree canopy that could theoretically be established.

## Project Background

The goal of the project was to apply the USDA Forest Service's TC assessment protocols to Honolulu. The primary data sources were Light Detection and Ranging (LiDAR) data acquired in 2009 (3.29ft) and Worldview-2 satellite imagery acquired in 2010 (1.65ft). This project was made possible by funding from the USDA Forest Service. The assessment was performed by the Spatial Analysis Laboratory (SAL) at the University of Vermont's Rubenstein School of the Environment and Natural Resources, in collaboration with Smart Trees Pacific and the USDA Forest Service's Northern Research Station.

## Amount of Tree Canopy in Urban Areas

An analysis of Honolulu's tree canopy based on land-cover data derived from high-resolution remotely-sensed data (Figure 1) found that urban areas contained 15,274 acres of tree canopy (termed Existing TC), representing 20% of all land in the urban zone. An additional 53% (40,984 acres) of the urban zones could theoretically be modified (termed Possible TC) to accommodate tree canopy (Figure 2). In the Possible TC category, 18% (13,760 acres) of the area was classified as Impervious Possible TC and 35% was Vegetated Possible TC (27,224 acres). Vegetated Possible TC, or grass and shrubs, is more conducive to establishing new tree canopy, but establishing tree canopy on areas classified as Impervious Possible TC will have a greater impact on water quality and summer temperatures.

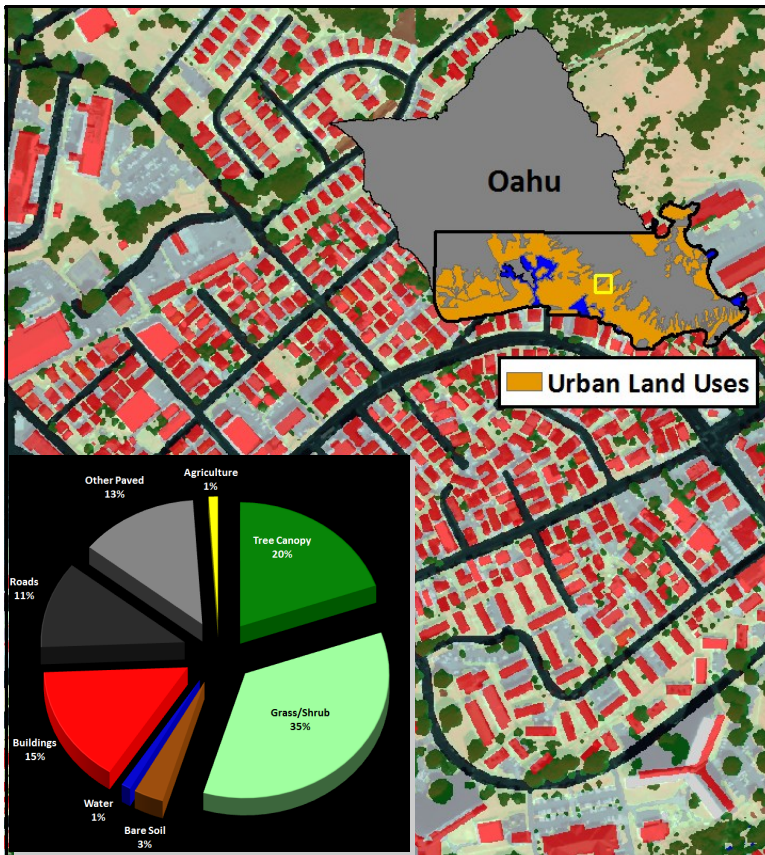


Figure 1: Land cover derived from high-resolution remote-sensing data for urban zones in Honolulu.

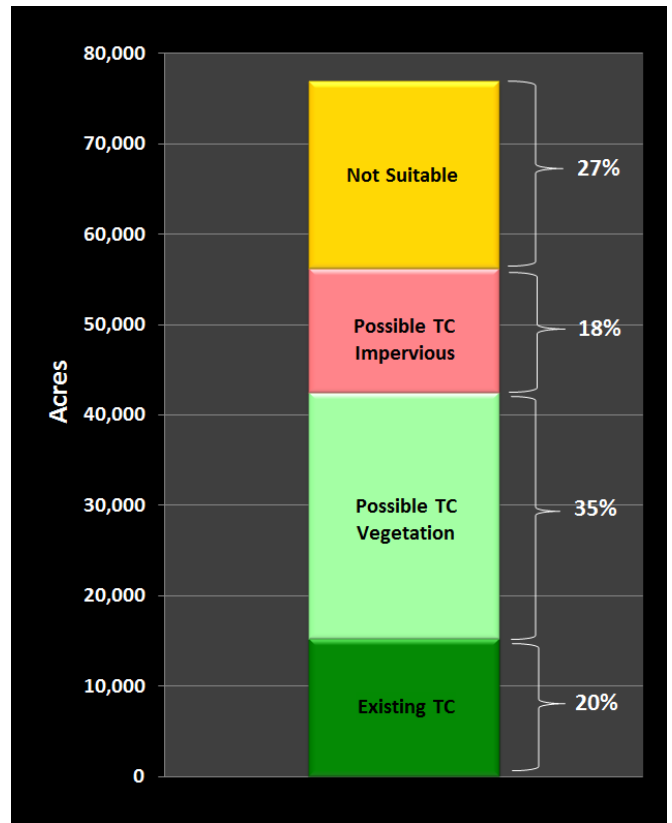


Figure 2: TC metrics for urban zones in Honolulu, based on % of land area covered by each TC type.

## Key Terms

- TC:** Tree canopy (TC) is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above.
- Land Cover:** Physical features on the earth mapped from aerial or satellite imagery, such as trees, grass, water, and impervious surfaces.
- Existing TC:** The amount of urban tree canopy present when viewed from above using aerial or satellite remote-sensing data.
- Impervious Possible TC:** Asphalt or concrete surfaces, excluding roads and buildings, that are theoretically available for the establishment of tree canopy.
- Vegetated Possible TC:** Grass or shrub area that is theoretically available for the establishment of tree canopy.

## Mapping Honolulu's Tree Canopy

Prior to this study, the only comprehensive remotely-sensed estimate of tree canopy for Honolulu was the 2001 National Land Cover Database (NLCD 2001). While NLCD 2001 is valuable for analyzing land cover at the regional level, it was derived from relatively coarse, 30-meter (98.4-ft) resolution satellite imagery (Figure 3a). Using high-resolution satellite imagery and LiDAR (Figure 3b) in combination with advanced automated processing techniques, this updated analysis mapped land cover to the scale of individual trees (Figure 3c). With a mean forest-canopy estimate of 11% for Honolulu's urban areas, NLCD underestimated tree canopy because it failed to capture many isolated trees.



Figure 3a, 3b, 3c: Comparison of NLCD 2001 to high-resolution land cover.

## Parcel Summary

After mapping land cover, Tree Canopy (TC) metrics were summarized for each property in Honolulu County's tax-parcel database (Figure 4). Existing TC and Possible TC metrics were calculated for each parcel, both in terms of total area and as a percentage of the land area within each parcel ( $TC \text{ area} \div \text{land area of the parcel}$ ).

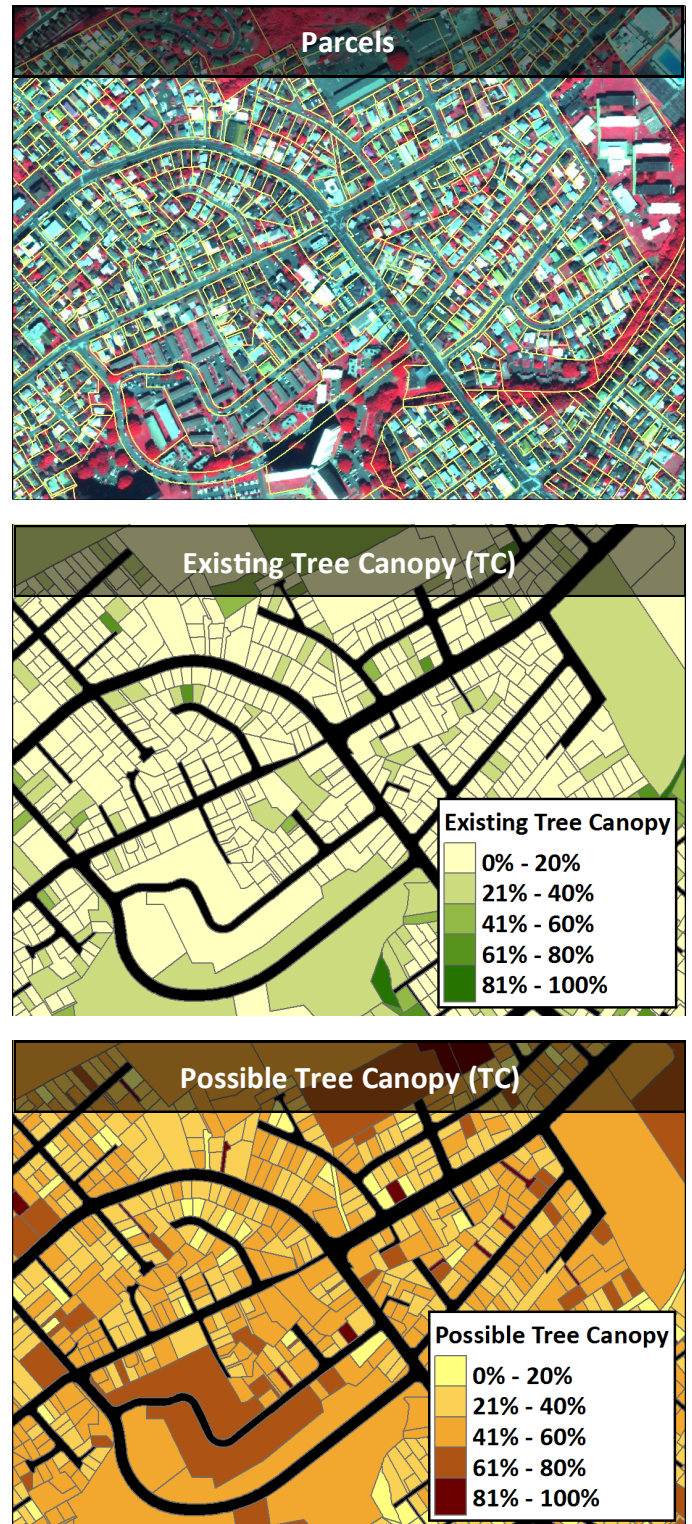


Figure 4a, 4b, 4c: Parcel-based TC metrics. TC metrics can be generated at the parcel level, allowing each property to be evaluated according to its Existing TC and Possible TC.

## Parks Analysis

A subset of the Honolulu County tax-parcel database focuses on parks owned by the county, including regional parks, nature parks, botanical gardens, golf courses, beaches, and neighborhood parks. Like the full database, this extract stores property boundaries and accompanying attribute information, and thus it serves as a fine-scale geography for examining local patterns in tree canopy (Figure 6). In particular, it enables evaluation of Existing and Possible TC between individual parks, providing site-specific information that is essential to the planning and management of tree-planting programs on these lands. For example, the Ala Puumalu Community Park has a comparatively large area of Possible TC, but much of its landscape is devoted to playing fields and other recreational amenities that provide important social benefits. Nonetheless, it may be possible to identify areas in this park (e.g., field or parking-lot margins) where additional trees are feasible and desirable.

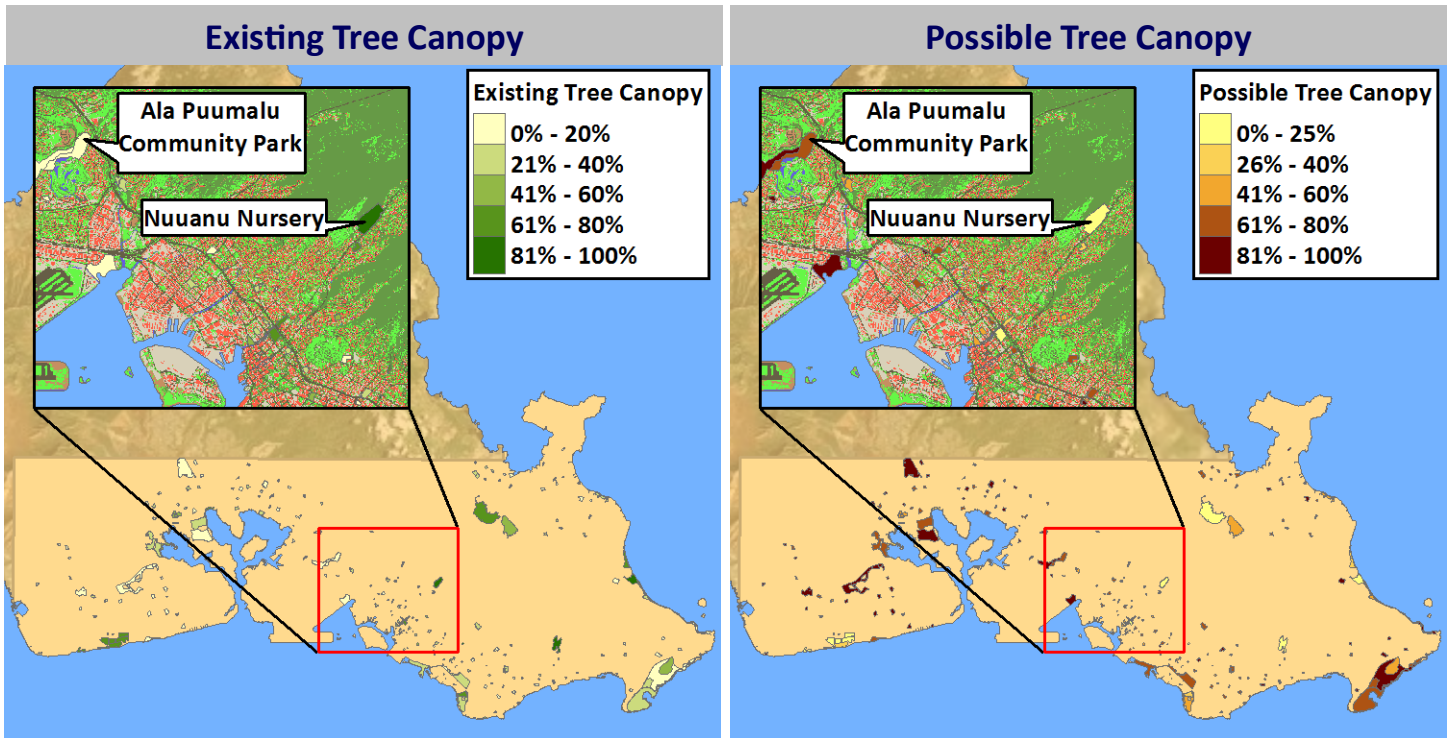


Figure 6. Tree-canopy assessment of Honolulu County's parks: Existing TC (left) and Possible TC (right) as a percentage of land within individual parks.

## Decision Support



Parcel-based tree-canopy metrics were integrated into Honolulu County's tax-parcel database (Figure 7). Decision makers can use GIS to query specific tree-canopy and land-cover metrics for a parcel or set of parcels. This information can be used to estimate the amount of tree loss in a planned development or set tree canopy improvement goals for an individual property.

Attribute	Value
Type	1
TMK	97024048
Address	1310 Waimano Home Rd.
Existing TC	13%
Possible TC	84%
Possible TC—Veg.	72%
Possible TC—Imp.	12%

Figure 7. GIS analysis of parcel-based TC metrics for decision support. In this example, GIS is used to select an individual parcel. The attributes for that parcel, including the parcel-based TC and land-cover metrics, are displayed in tabular form providing instant access to relevant information.

# Zoning

An analysis of Existing and Possible tree canopy by zoning category was conducted using Honolulu County’s zoning layer (Figure 5, Table 1). For each zoning district, Tree Canopy (TC) metrics were calculated as a percentage of all land in the study area (% Land), as a percentage of land area in the specified zoning category (% Category), and as a percentage of the area for TC type (% TC Type). Outside of the various Preservation Districts, the Residential and Agricultural Districts contained the largest proportion of Existing TC, emphasizing the importance of trees on privately-owned lands. The Preservation Districts also contained the largest proportions of Possible TC, where tree canopy could theoretically be expanded, but additional opportunities occur in the Residential, Industrial and Agricultural zones.

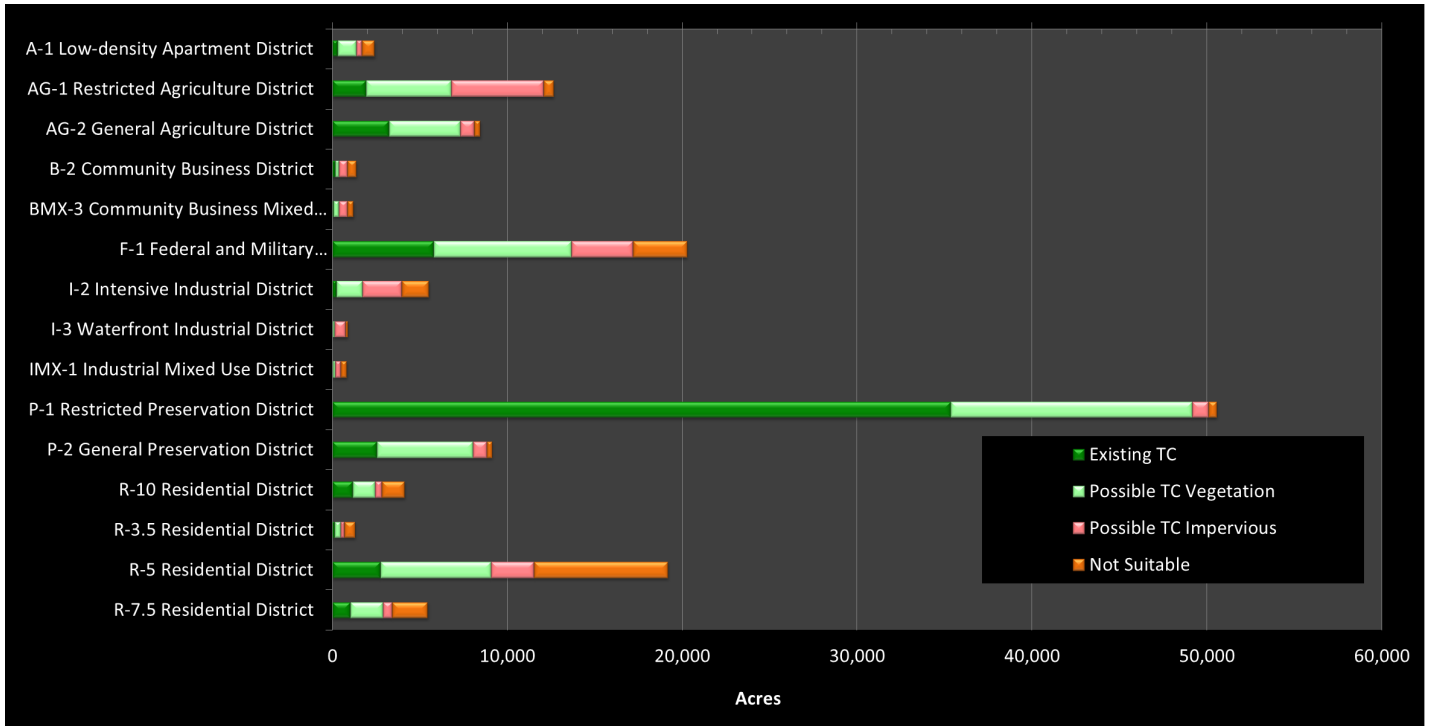


Figure 5: Tree Canopy (TC) metrics summarized by selected zoning classes.

Zoning	Existing TC			Possible TC Vegetation			Possible TC Impervious		
	% Land	% Category	% TC Type	% Land	% Category	% TC Type	% Land	% Category	% TC Type
A-1 Low-density Apartment District	0%	12%	1%	1%	44%	2%	0%	13%	2%
AG-1 Restricted Agriculture District	1%	15%	3%	3%	39%	10%	4%	42%	26%
AG-2 General Agriculture District	2%	38%	6%	3%	48%	8%	1%	10%	4%
B-2 Community Business District	0%	12%	0%	0%	15%	0%	0%	34%	2%
BMX-3 Community Business Mixed Use District	0%	6%	0%	0%	24%	1%	0%	41%	2%
F-1 Federal and Military Preservation District	4%	29%	10%	5%	39%	16%	2%	17%	17%
I-2 Intensive Industrial District	0%	4%	0%	1%	27%	3%	2%	40%	11%
I-3 Waterfront Industrial District	0%	3%	0%	0%	14%	0%	0%	71%	3%
IMX-1 Industrial Mixed Use District	0%	5%	0%	0%	15%	0%	0%	36%	1%
P-1 Restricted Preservation District	24%	70%	63%	9%	27%	27%	1%	2%	4%
P-2 General Preservation District	2%	28%	5%	4%	60%	11%	1%	9%	4%
R-10 Residential District	1%	28%	2%	1%	31%	3%	0%	9%	2%
R-3.5 Residential District	0%	10%	0%	0%	28%	1%	0%	14%	1%
R-5 Residential District	2%	14%	5%	4%	33%	12%	2%	13%	12%
R-7.5 Residential District	1%	19%	2%	1%	34%	4%	0%	10%	3%

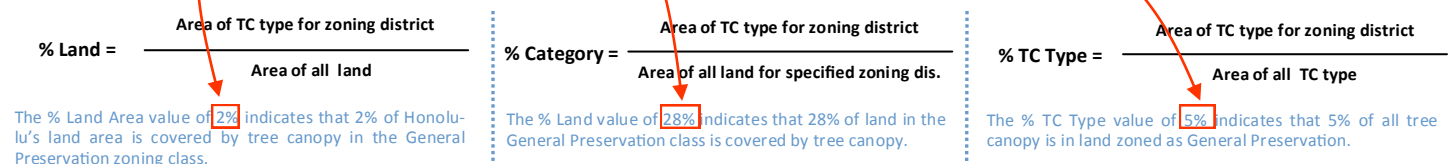


Table 1: TC metrics were summarized by selected zoning categories. For each zoning class, TC metrics were computed as a percentage of all land in the city (% Land), as a percentage of land in the specified zoning district (% Category), and as a percentage of the area for TC type (% TC Type).

## Comparison of Urban Areas

At a coarse scale, it is possible to compare the distribution of tree canopy in Honolulu’s major urban zones (Figures 8, 9). In the primary urban area of Honolulu, about 20% of the land categorized as an urban land use is occupied by tree canopy. In the Makakilo\Kapolei\Honokai Hale (MKHH) area, which encompasses many former agricultural lands, tree canopy occupies only a slightly smaller proportion (16%) of lands considered urban. Although the city contains a larger proportion of land unsuited for expanding tree canopy, and its proportion of landscape features categorized as Possible TC is correspondingly smaller (46% vs. 71% for MKHH), both areas likely contain many opportunities for tree-planting programs. However, the Possible TC designation does not dictate where trees should be planted; it instead shows areas where it is theoretically possible to modify existing landscape features to accommodate more trees. Actual planting programs will require more detailed prioritization schemes that not only incorporate site-specific land-cover data but also consider economic and social needs. This TC assessment is an essential first step that quantifies current conditions, setting the stage for subsequent efforts that focus on specific tree-canopy goals.

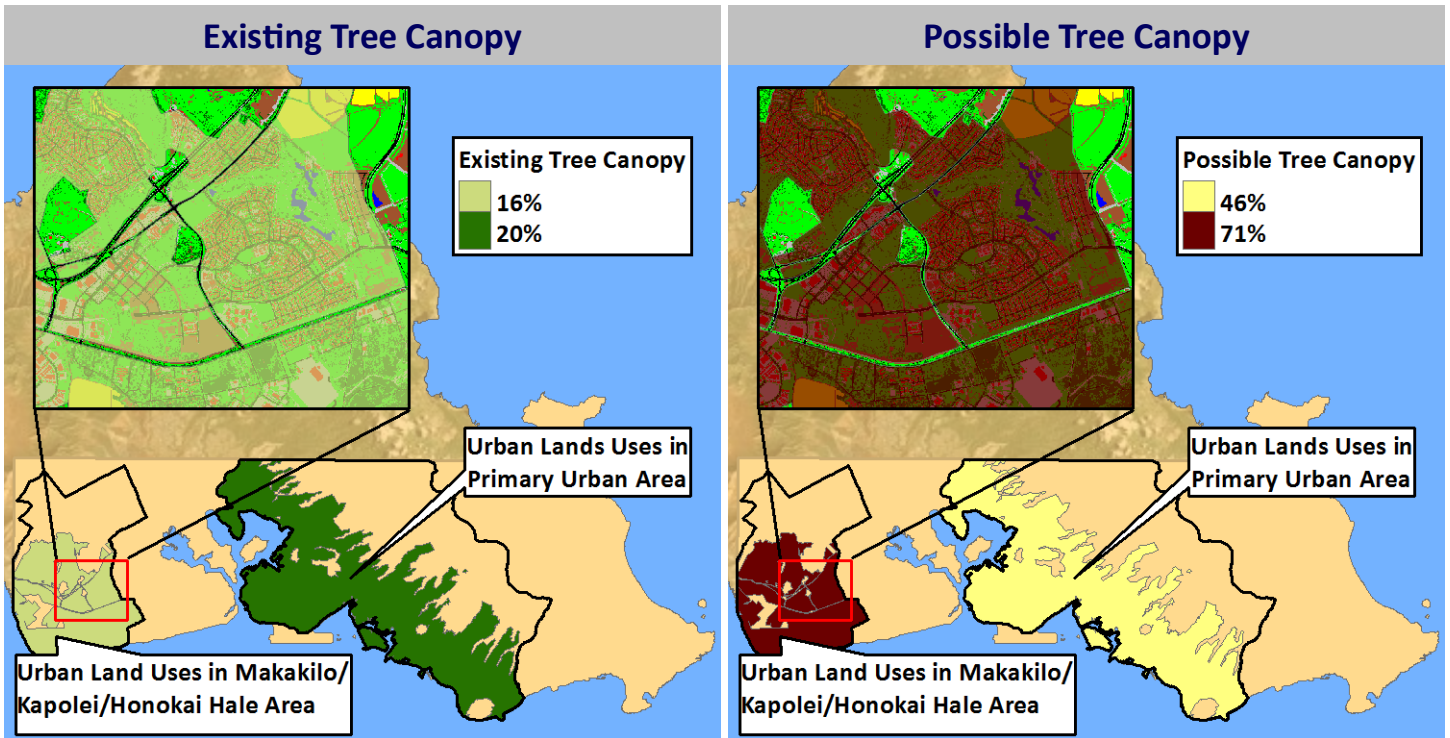


Figure 8. Existing TC (left) and Possible TC (right) as a percentage of lands considered urban in Honolulu’s major urban areas.

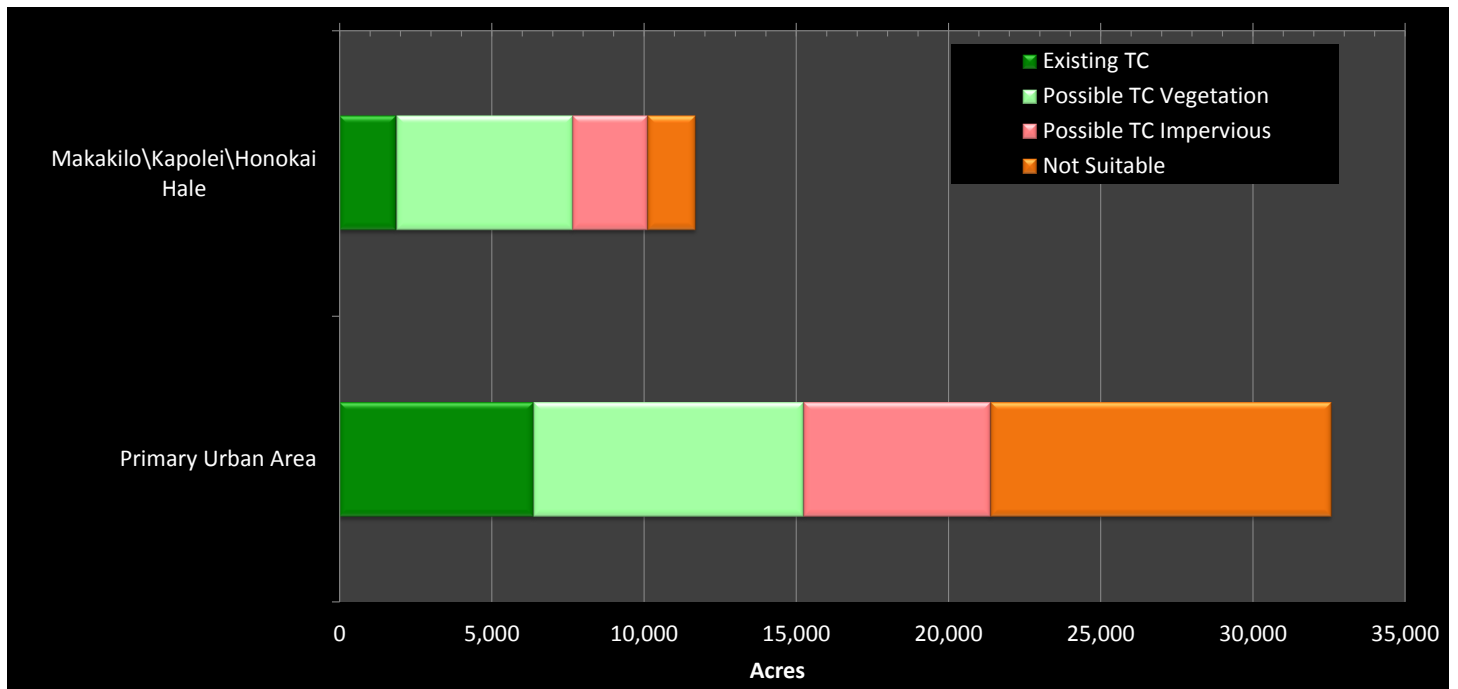


Figure 9. Tree-canopy assessment acreages for lands considered urban in Honolulu’s major urban areas. The “not suitable” category includes buildings and roads, where establishment of new tree canopy is unlikely.

## Council Districts

In addition to zoning, parcel, and municipal analyses, tree-canopy estimates can be calculated for political boundaries (Figures 10, 11). When summarized by council districts, for example, the highest proportion of Existing TC was located in District 6, and this district also contained the lowest proportion of Possible TC. Although this district includes heavily-urbanized areas in Honolulu, it extends into upland areas that contain expanses of contiguous tree cover. In contrast, the adjacent District 7 contained the lowest proportion of tree canopy and comparatively high proportions of Possible TC. However, this district includes Honolulu International Airport and extensive Joint Base Pearl Harbor-Hickam military installations, suggesting that opportunities for expanding tree canopy may be limited in this area. Western sections of the study area, including Kapolei, have the highest proportion of Possible TC, further supporting the observation that tree-planting efforts may be effective in this locale. However, agriculture is still an important land use here, especially in District 9, and protection of local farms and plantations may be an important community goal in its own right.

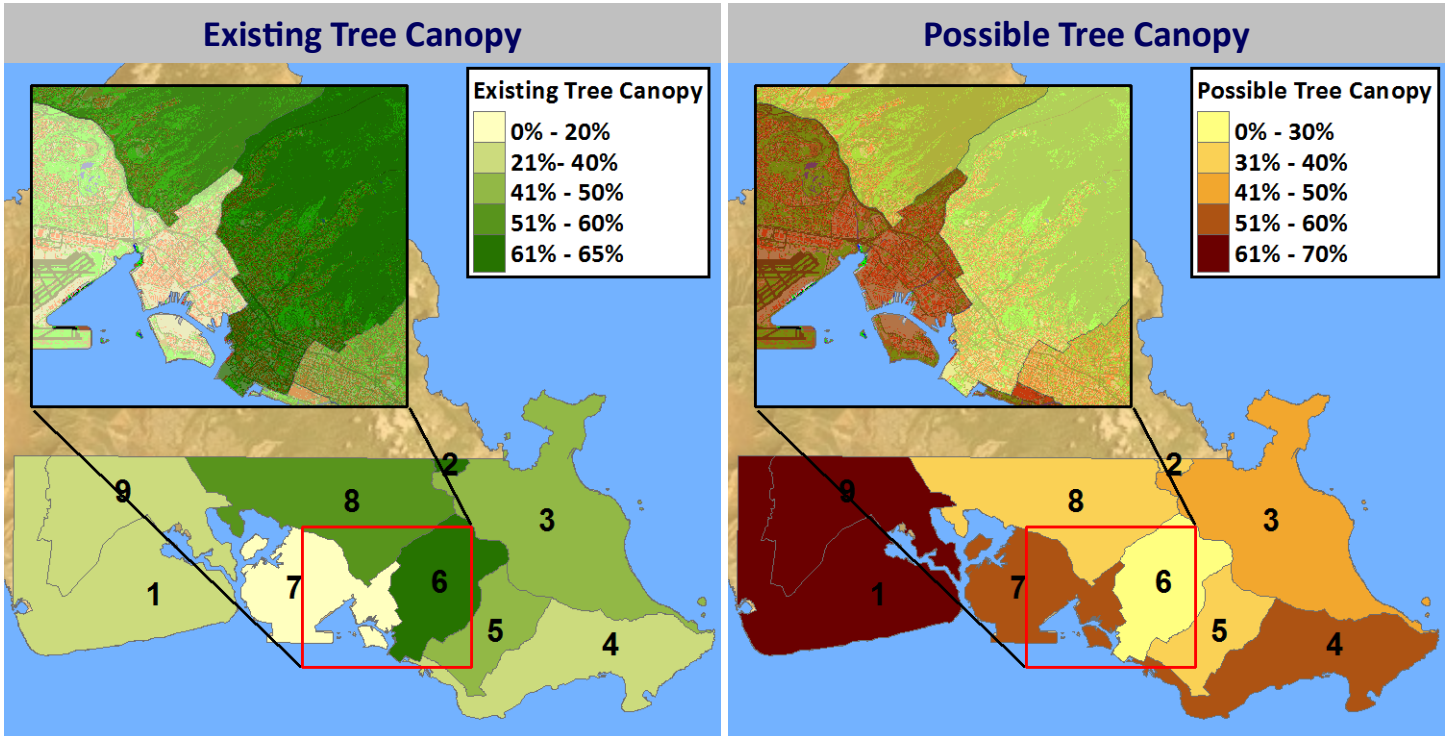


Figure 10. Existing TC (left) and Possible TC (right) as a percentage of land for council districts in the Honolulu study area.

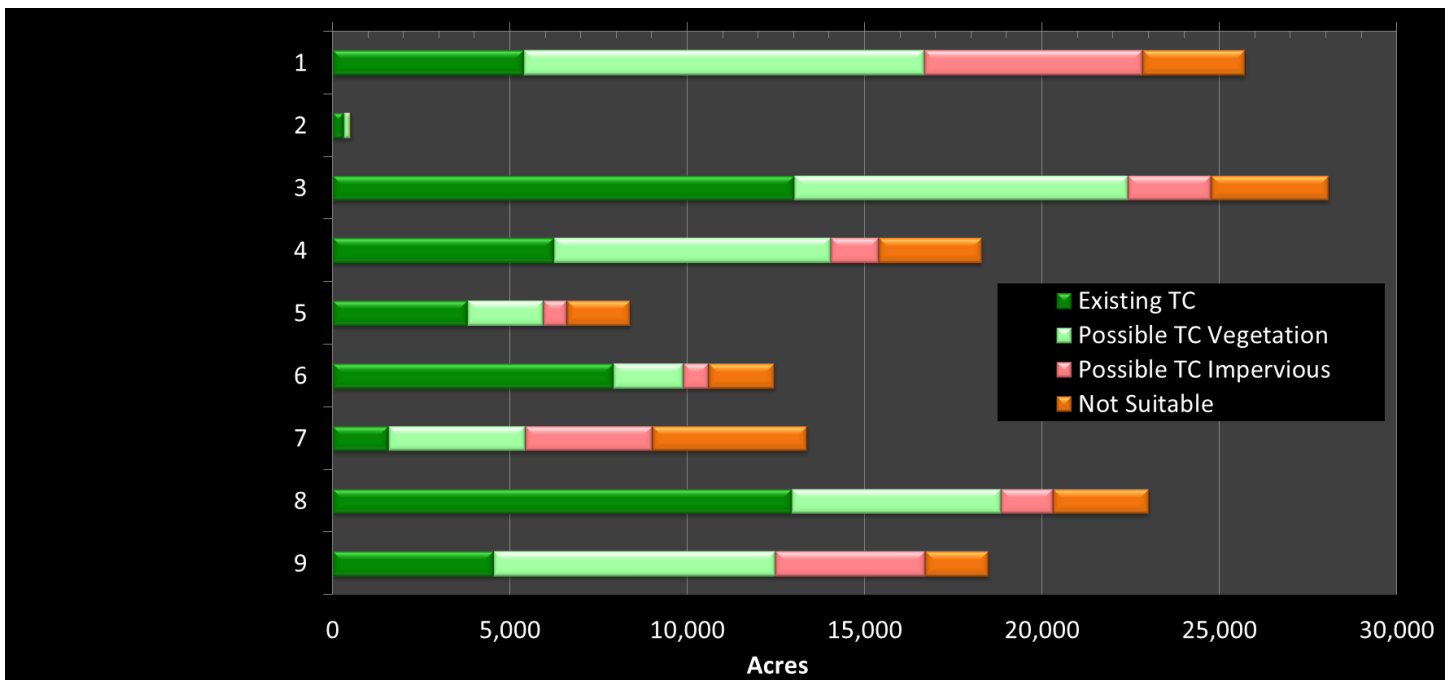


Figure 11. Tree-canopy assessment acreages by council district. The “not suitable” category includes buildings and roads, where establishment of new tree canopy is unlikely.

## Rainfall Zones

Landscape-level geographies that focus on natural physical features and climate can also be considered, including rainfall patterns. For example, tree-canopy patterns can be summarized by annual rainfall totals from the Rainfall Atlas of Hawaii (Giambelluca et al. 2011; <http://rainfall.geography.hawaii.edu/>) divided into five simple categories (Figures 12, 13). Although both Existing and Possible TC seem strongly dependent on rainfall, topography and land use are the likely determinants behind these patterns; fewer trees occur in dry, flat lowland zones because these areas have been the historical focus of urban and agricultural land uses while wet, steep upland zones have more extensive forest cover because they have remained largely undeveloped. However, these rainfall zones underscore the need to consider species selection when designing tree-planting programs. Trees planted in the lowland regions that receive comparatively low rainfall should be tolerant of the drier conditions prevalent in these locales, while planting programs in higher elevations should focus on species better adapted to steeper, wetter terrain. In the driest locations, native cactus species may actually be better adapted to environmental conditions than trees.

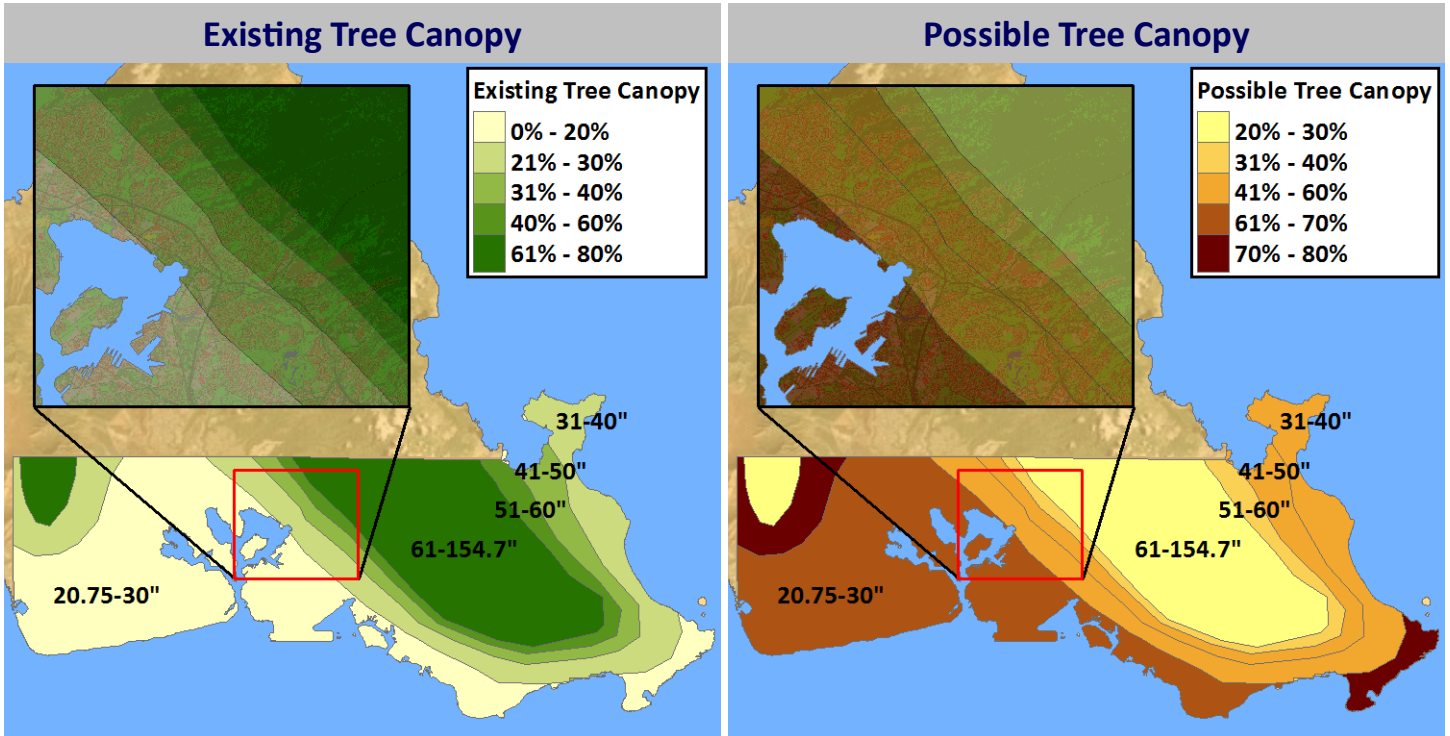


Figure 12. Existing TC (left) and Possible TC (right) as a percentage of land for annual rainfall zones (inches) in the Hono lulu study area.

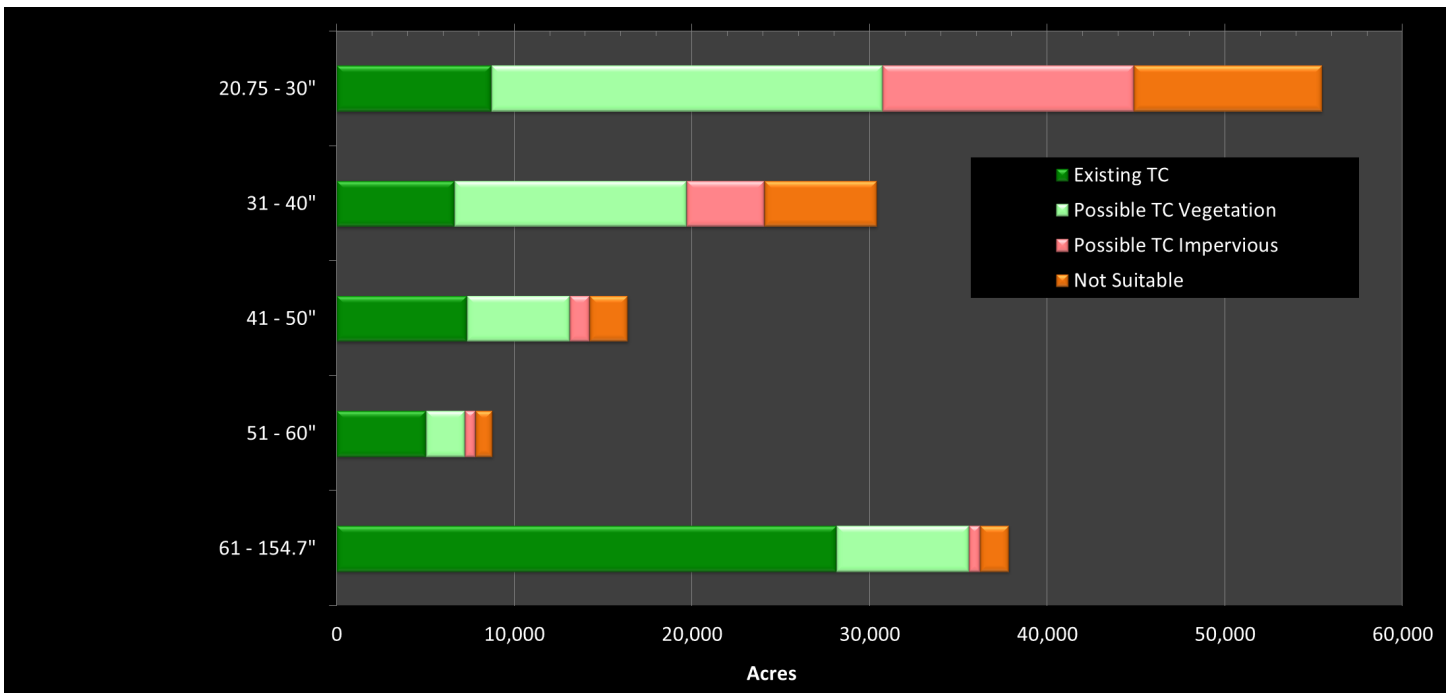


Figure 13. Tree-canopy assessment acreages by annual rainfall zones (inches) . The "not suitable" category includes buildings and roads, where

## Coastal Elevation Zones

The relationship between elevation and tree canopy is also important at finer scales, especially in coastal zones susceptible to flooding or tsunamis; research has indicated that some types of coastal vegetation may mitigate the damaging effect of tsunamis by reducing the energy of waves surging inland (e.g., Tanaka 2009). While the datasets developed as part of this tree-canopy assessments cannot address whether Honolulu’s tree cover can serve as an effective bioshield, it is possible to examine the current distribution of trees in a series of elevation zones above sea level (Figures 14, 15). A strong relationship in total area per zone is readily apparent, with the lowest zones above sea level containing the most land, and Existing Tree Canopy is a proportionately-small component of these zones. This relative lack of trees is especially noticeable in waterfront industrial areas, where options for planting trees may be limited (e.g., Honolulu International Airport). However, the large proportions of Possible Tree Canopy in each zone nonetheless suggest that opportunities yet exist for expanding coastal tree cover on Honolulu, and scientists and emergency planners will be able to use this tree-canopy assessment in their subsequent research.

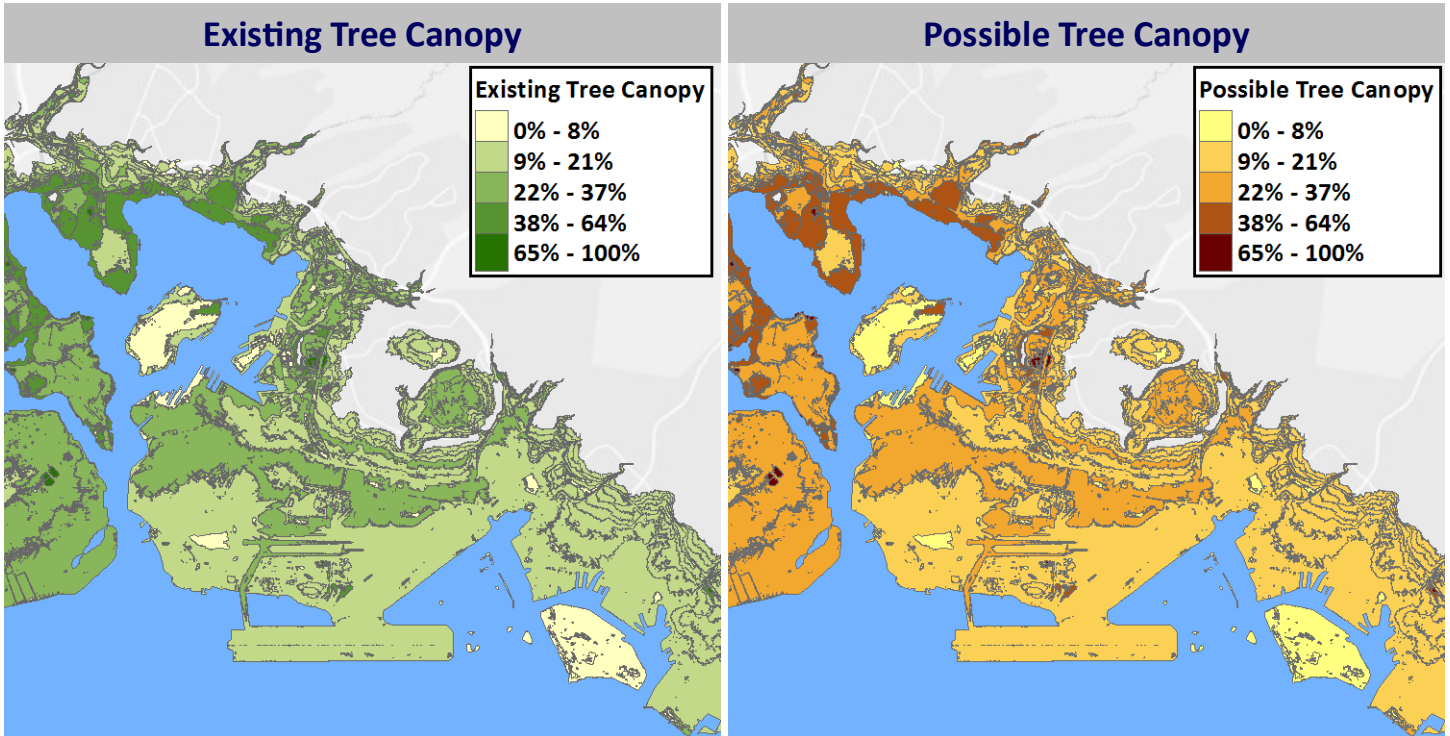


Figure 14. Existing TC (left) and Possible TC (right) as a percentage of land for coastal elevation zones in the Honolulu study area.

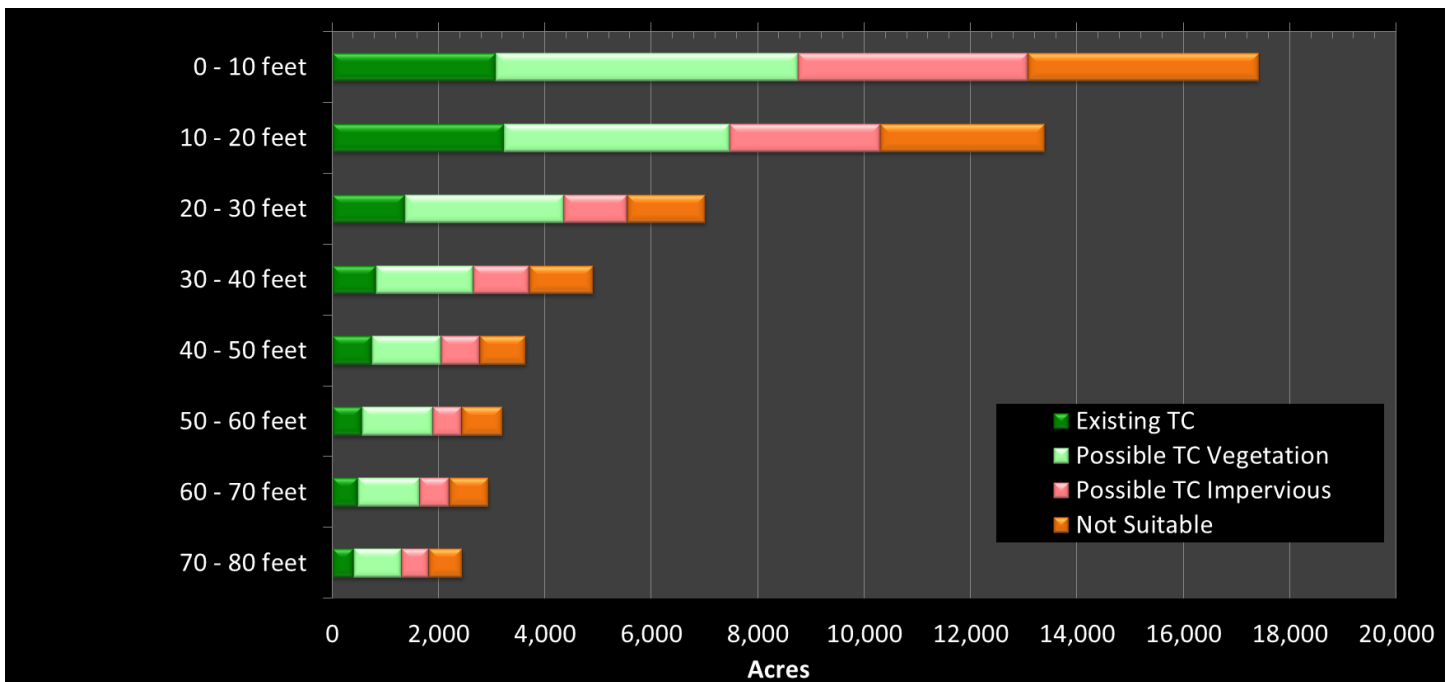


Figure 15. Tree-canopy assessment acreages by coastal elevation zone above sea level. The “not suitable” category includes buildings and roads, where establishment of new tree canopy is unlikely.



## Tree Canopy Opportunity Index

In addition to simple descriptive statistics, more sophisticated techniques can help identify areas of the city where tree-planting and stewardship programs would be most effective. One approach is to focus on spatial clusters of Existing and Possible TC. When a 1,000-foot grid network is superimposed on the land-cover map (Figure 16a), it is possible to map regions of the study area where high values of Existing TC are tightly clustered (Figure 16b). A similar map was constructed for Possible TC (Figure 16c). A single index was created by subtracting the percentage of Existing TC per grid cell from Possible TC, which produced a range of values from -1 to 1. When clustered, this tree canopy opportunity (TCO) index highlights areas with high Possible TC and low Existing TC (Figure 16d); these areas theoretically offer the best places to strategically expand Honolulu's tree canopy and to increase its many attendant benefits. As with all such analyses, however, landscape context must be evaluated before setting priorities; for example, one of the areas with high TCO Index encompasses part of Honolulu International Airport, where opportunities for planting additional trees are likely quite limited (or prohibited entirely) by landscaping restrictions.

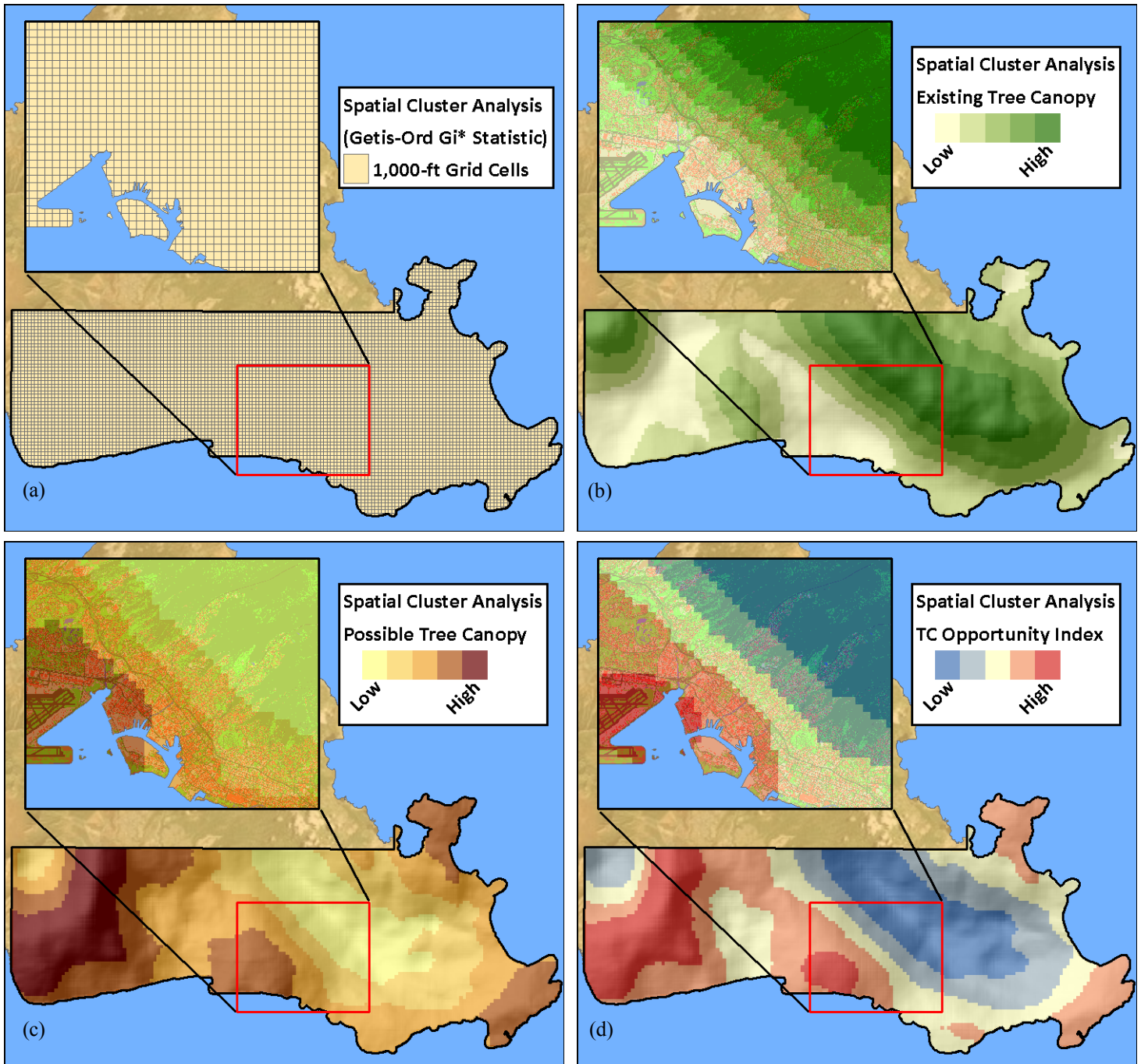


Figure 16: (a) Grid network (1,000-foot cells) superimposed on land-cover map for Honolulu and then used in spatial cluster analyses; (b) Spatial clustering of Existing TC in Honolulu; dark green areas are highly clustered and have high Existing TC values; (c) Spatial clustering of Possible TC in Honolulu; dark red areas are highly clustered and have high Possible TC values; and (d) Spatial clustering of a combined index of Existing and Possible TC; red areas theoretically provide the best opportunities for expanding tree canopy.

## Conclusions

- Honolulu’s landscape is a complex mosaic of urban land uses, agriculture, and undeveloped upland areas; 20% of the lands considered urban is occupied by tree canopy. These trees help moderate stormwater runoff, ambient air temperatures, and air pollution while also providing aesthetic, economic, and recreational benefits.
- The Possible TC designation includes features that could be modified to accommodate additional trees, including lawns, the margins of fields, sidewalks, street medians, and parking lots. Across Honolulu, this category includes 53% of the lands considered urban. However, it is important to remember that this analysis does not specify exactly where trees should be planted; rather, it identifies areas that theoretically could support additional trees given the right combination of social, political, economic, legal, and environmental conditions. It is also important to remember that it may be socially and economically desirable to keep certain lands as open, including recreational playing fields and agriculture.
- A primary advantage of this assessment protocol is that it can summarize tree canopy according to many different landscape geographies, which helps elucidate current TC patterns and to prioritize tree-planting efforts. These geographies range from fine-scale descriptors such as individual ownership parcels to coarse-scale political boundaries such as council districts.
- Governmental and institutional entities likely own much of the land containing Possible TC and thus may offer the most efficient options for expanding tree canopy. However, small private landowners control an important component of the existing urban tree cover and could offer many additional opportunities for planting trees.
- In addition to social geographies, tree-canopy patterns can be summarized according to physical features such as land use and topography. The data provided by this tree-canopy assessment can be used by other researchers to better understand the environmental factors affecting tree cover and to identify areas where tree-planting programs will be most beneficial.

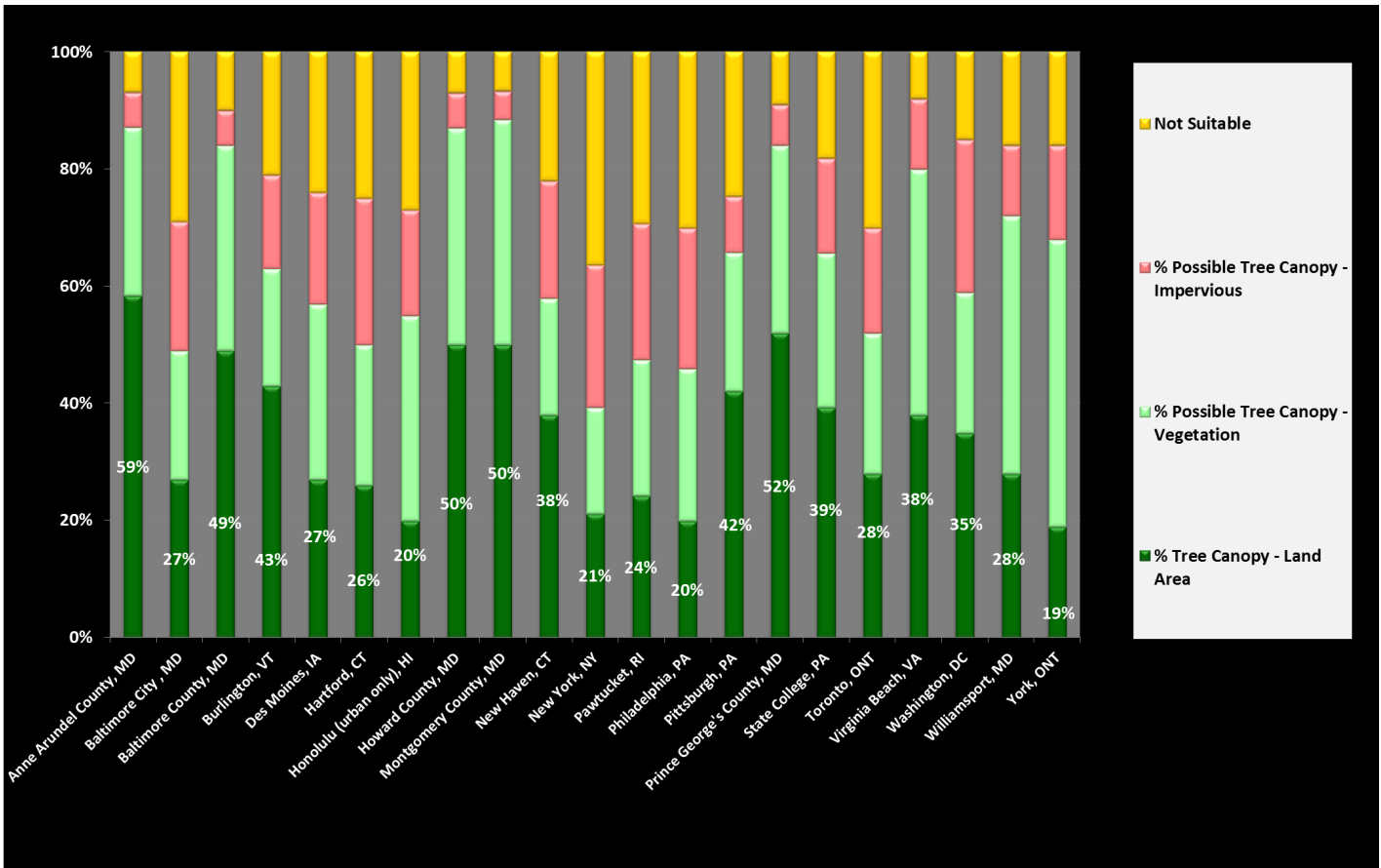


Figure 17: Comparison of Existing and Possible Tree Canopy with other selected cities and counties that have completed Tree Canopy Assessments.

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### Additional Information

Funding for the project was provided by the USDA Forest Service. More information on Tree Canopy Assessments can be found at the following websites:  
<http://nrs.fs.fed.us/urban/utc/>  
<http://smarttreespacific.org/>

