Marin County Urban Forest Canopy Cover Assessment

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Image: http://www.marinmodern.com/Fairfax-Real-Estate.php

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Glossary

AFUE	Annual fuel utilization efficiency
Agri	Agriculture land use
BLD	Building
BS	Bare soil land cover
BSDV	Bare-soil and dry (non-woody) vegetation land cover combined
BVOC	Biogenic volatile organic compounds
Comm	Commercial land use
ESRI	Environmental Systems Research Institute, Inc., Redlands, CA
GIS	Geographic Information System
Impervious	all impervious that were not buildings (used for the accuracy assessment)
Ind	Industrial land use
LiDAR	Light Detection And Ranging
Mixed	Mixed land uses
MultiFam	Multi-family or high-density residential land use
NAIP	National Agricultural Imagery Program
NO_2	Nitrogen dioxide
O_3	Ozone
OBIA	Object-based image analysis
OpenSpace	Open Space
Other Imp	Other impervious surfaces that are not in the building or road class
PM10	Particulate matter of <10 micron diameter
PQP	Public/Quasi-Public land
PTPS	Potential tree planting sites
PUTC	Potential UTC
RS	Remote sensing
RU	Resource unit
SingleFam	Single -family or low-density residential land use
TF	Transfer function
UTC	Urban tree canopy
VOC	Volatile organic compound

Executive Summary

The greater Marin County contains 520 square miles and is home to nearly 253,000 people (www.city-data.com). This study focused on 77 square miles in Marin County that is urbanized and home to about 219,000 people, 86% of Marin's population. Urban growth is placing higher concentrations of people in urban environments where greenspace is a critical component to quality of life. Finding adequate space for trees in these densely engineered developments can be a challenge. These problems urgently need solutions. Urban forestry is one solution because it is integral to land use planning, land value and local tax base increases, job training and employment opportunity, city services cost reduction, and public safety. Urban forest management can mitigate water shortages, conserve energy and improve air quality. Expanding the urban forest through judicious tree planting and stewardship activities can insure long term environmental, economic, and health benefits to local communities and maximize the return on investment.

This study provides up-to-date information on the extent and potential of Marin's urban forest. It quantifies the distribution of current tree canopy cover and maps locations of potential tree planting sites. Also, the study estimates the dollar value of ecosystem services and property values provided by the current and future urban forest.

Urban tree canopy (UTC), defined as the "layer of leaves, branches and stems that cover the ground" (Raciti et al. 2006a), is the metric used to quantify the extent, function, and value of Marin's urban forest. To calculate the benefits of the urban forest canopy, analyses of tree-building distributions were combined with UTC mapped across the study area from remote sensing. The ecosystem services and property value increases associated with UTC were calculated with numerical models developed by the US Forest Service. Services per unit UTC were applied to the measured UTC and monetized to calculate their annual value for existing and additional UTC (i.e., runoff reduction, air quality, carbon dioxide removal, property values, and building energy use savings).

Marin's urban forest is extensive, covering 36.6% of the 200 km^2 study area (Table 1). Urban tree canopy ranged from 20% in Lagunitas-Forest Knolls CDP to greater than 60% in Ross and San Geronimo CDP. Impervious surfaces such as roads, buildings, and parking lots accounted for 28% of the land area, while irrigated grass, bare soil, and dry vegetation covered 25%. San Francisco State University's land cover classification accuracy assessment found that the overall accuracy was 87%. The user's accuracy for UTC, the focus of this study, was 92%. This value is above the 90% standard set for the study

There are approximately 1.9 million trees in Marin's urban forest, assuming an average crown diameter of 22.8 ft. The average number of trees per acre in Marin is 38.9, which exceeds values reported for Sacramento (16.1), Los Angeles (19.9), Pasadena (24.1) and Minneapolis (26.4). The average number of trees per capita is 8.8, also much higher than Pasadena (2.7), Minneapolis (2.6), Los Angeles (1.3), Chicago (1.3) and Philadelphia (1.4).

Marin's urban forest produces ecosystem services and property value increases valued at $273 million annually. The largest benefit, $198 million, is for increased property values and other intangible services. Building shade and air temperature decreases from trees reduce residential air condition demand by 319,000 MWh, saving $59 million in cooling costs each year. The existing urban forest intercepts 1.5 billion gallons of rainfall annually, which reduces stormwater runoff management costs valued at $8.5 million. If carbon dioxide sequestered and emissions avoided from cooling savings by the existing trees, a total of 120,996 tons, were sold at $10 per ton, the revenue would be $1.2 million. Finally, Marin's urban forest filters a net total of 391 tons of air pollutants from the air annually.

Marin County contains approximately 425,622 potential tree planting sites (PTPS) assuming larger (50-ft crown diameter) trees in non-irrigated grass and bare soil and medium (30-ft crown diameter) trees in irrigated grass. Planting half of the available planting sites, 212,811, would increase UTC from 36.6% to 45.7% once these trees mature, assuming that current UTC remains stable and program tree sites remain fully stocked. The number of vacant sites to be planted ranged from 213 in Alto CDP (UTC 28.8%) to 53,033 in Novato (UTC 31.3) (Table 1).

Achieving the targeted 9.1% UTC increase will pay many dividends. The annual worth of ecosystem services and property values will increase by nearly 21% or $56.2 million, from $273 million to $328.8 million. The value of increased annual property values and other intangible services is projected to be $40.7 million alone. Reduced demand for 63,480 MWh of electricity for air conditioning is expected to save another $11.8 million in cooling costs. Annual savings for lowered stormwater management costs from an additional 381 million gallons of rainfall interception is projected to be $40.7 million. Trees in the additional sites will diminish atmospheric carbon dioxide by 29.5 thousand tons, valued at $295,150 annually. The additional UTC will remove another 84 tons of pollutants from the air.

Expansion of the UTC from 36.6 to 45.7% is projected to result in total services valued at $328.8 million annually from approximately 2.1 million trees. The average annual value of $154 per tree is comparable to results for the same services reported for other cities. This is a very conservative estimate of service value as it does not fully capture all benefits associated with increased UTC, such as job creation, improved human health and fitness, wildlife habitat, and biodiversity.

The values for these services have been expressed in annual terms, but trees provide benefits across many generations. Moreover, the benefits trees provide become increasingly scarce and more valuable with time. To enable tree planting and stewardship to be seen as a capital investment, the asset value of trees in Marin was calculated. The annual flows of realized benefits from trees were converted into their net present value, which is a discounted sum of annual future benefits. Discounting future services to their present value incorporates the time value of money and the opportunity cost of investment. The farther ahead in time one goes, the less value a dollar has. A benefit derived in 50 years is worth far less than the same benefit today. By applying this method to the future stream of ecosystem services, the urban forest's asset value is calculated in today's dollars.

Discount rates of 4.125%, which is applied by the US Army Corps of Engineers for large projects, and 0% were used over 100 years for Existing UTC, Additional UTC, and Existing plus Additional UTC. Some economists argue that natural capital has a lower discount rate because the benefit stream is more certain over longer periods of time.

The asset value of Marin's existing urban forest is $6.5 billion, or $3,380 per tree, calculated at a 4.125% discount rate for the next 100 years. At zero discount rate, the region's urban forest asset value is estimated at $27.3 billion. If UTC is increased to 45.7% over the next 30 years, the urban forest's asset value increases to $7.9 billion and $31.6 billion, assuming 4.125% and 0% discount rates, respectively. Hence, the ecosystem services produced by the region's urban forest provide a considerable stream of benefits over time, just as a freeway or other capital infrastructure does. Quantifying the asset value of this "green infrastructure" can help guide advancement towards a sustainable green economy by shifting investments towards the enhancement of natural capital.

Results from this study can be used to:

- Communicate the ecological and economic value of the existing urban forest
- Establish tree planting and UTC targets for Council Districts
- Describe the level of benefits obtained by reaching these targets
- Track changes in UTC that reflect progress made reaching targets
- Link changes in UTC to causal drivers such as levels of community tree planting, drought, pests, storms, and vandalism

Marin is a vibrant county that has invested in its urban forest as it has grown. The task ahead is to better integrate the green infrastructure with the gray infrastructure by targeting tree planting and stewardship activities to maximize their environmental and human health impacts. This study provides information that can be used to plan, prioritize and implement new urban forestry programs. In so doing, Marin's regional urban forest will become larger, more resilient, and better able to meet the challenges that loom ahead.

Table 1. Existing and additional urban tree canopy (UTC), estimated tree numbers, and monetized value of ecosystem services produced.

Jurisdiction	No. existing trees	No. additional sites plantes	Total tree sites planted	Existing stocking level (%)	Future stocking level (%)	Change in stocking (%)	Existing UTC (%)	Future UTC (%)	Annual value of existing ecosystem services ($1M)	Annual value of additional ecosystem services ($1M)	Existing + additional ecosystem services ($1M)
Alto CDP	2,484	213	2,697	85.5	92.8	7.3	28.8	34.2	0.42	0.07	0.49
Belvedere city	16,888	739	17,627	92.0	96.0	4.0	40.0	43.5	3.01	0.25	3.26
Black Point-Green Point CDP	67,650	9,265	76,915	78.5	89.3	10.8	45.8	59.5	10.53	2.88	13.40
Corte Madera town	55,437	7,190	62,627	79.4	89.7	10.3	31.8	40.0	8.48	1.64	10.12
Fairfax town	68,125	1,640	69,765	95.4	97.7	2.3	59.1	63.2	10.81	0.67	11.49
Kentfield CDP	94,961	2,651	97,612	94.7	97.4	2.6	55.8	59.4	16.40	0.89	17.29
Lagunitas-Forest Knolls CDP	4,340	1,297	5,637	62.6	81.3	18.7	19.8	40.2	0.44	0.41	0.85
Larkspur city	57,393	6,153	63,546	82.4	91.2	8.8	30.9	38.1	8.92	2.04	10.95
Lucas Valley-Marinwood CDP	42,139	4,406	46,545	82.7	91.4	8.6	33.7	42.7	5.21	1.23	6.44
Marin City CDP	5,787	832	6,619	77.7	88.9	11.2	24.8	33.3	0.76	0.21	0.97
Mill Valley city	133,999	7,246	141,245	90.2	95.1	4.9	47.1	53.2	19.55	1.80	21.34
Novato city	350,172	53,033	403,205	76.8	88.4	11.6	31.3	42.9	53.55	17.32	70.88
Ross town	58,993	1,159	60,152	96.2	98.1	1.9	67.5	70.6	11.00	0.49	11.49
San Anselmo town	87,580	3,245	90,825	93.1	96.6	3.4	49.4	55.2	15.44	1.59	17.03
San Geronimo CDP	11,157	345	11,502	94.2	97.1	2.9	62.9	68.4	2.08	0.15	2.24
San Rafael city	258,146	33,928	292,074	79.2	89.6	10.4	28.5	36.9	33.73	7.60	41.33
Santa Venetia CDP	17,693	2,751	20,444	76.3	88.2	11.9	26.5	35.6	2.25	0.90	3.15
Sausalito city	35,495	2,101	37,596	89.4	94.7	5.3	34.9	39.0	5.25	0.47	5.72
Sleepy Hollow CDP	49,718	3,543	53,261	87.5	93.8	6.2	45.2	55.3	7.12	1.33	8.45
Strawberry CDP	28,165	3,729	31,894	79.1	89.6	10.5	30.8	39.2	4.09	1.05	5.14
Tamalpais-Homestead Valley CDP	93,050	4,089	97,139	91.9	96.0	4.0	50.1	55.3	14.32	1.35	15.68
Tiburon town	68,960	14,562	83,522	70.3	85.2	14.8	30.7	43.3	10.68	3.10	13.79
Unincorporated	272,615	47,125	319,740	74.3	87.2	12.8	32.6	45.6	22.01	8.06	30.07
Woodacre CDP	40,071	1,569	41,640	92.7	96.4	3.6	57.8	65.0	6.56	0.70	7.27
Total	**1,921,018**	**212,811**	**2,133,829**	**81.9**	**90.9**	**9.0**	**36.3**	**45.7**	**272.63**	**56.20**	**328.83**

Introduction

Rapid growth of the San Francisco Bay Area is accelerating air pollution along with water and energy demand. These problems urgently need solutions. Urban forestry is integral to land use planning, mitigating water shortages, conserving energy, improving air quality, enhancing public health programs, increasing land values and local tax bases, providing job training and employment opportunities, reducing costs of city services, and increasing public safety. Despite the relevance of urban forest ecosystems to the environmental and economic health of Bay Area communities, few programs have the funds needed to adequately plan and manage their urban forest resources. In addition, they rarely have baseline data on their existing urban canopy cover and potential tree planting sites (PTPS). This study extends a previous State of the Urban Forest Report on the San Francisco Bay Area by focusing on Marin County. The goal is to demonstrate how field data, GIS data sets, and high resolution remote sensing can be combined to describe urban forest structure, function, and value at a regional scale. In this study we mapped Marin County's urban tree canopy cover (UTC), estimated the number of existing trees, identified available planting sites, prioritized tree planting sites based on program goals, and calculated future ecosystem services and property value increases from planting an additional tree sites. This baseline information will assist the California Urban Forest Council and local jurisdictions in implementing their urban forestry programs, whereby they can serve as a model for others around the state.

The project included two phases. Phase 1 was conducted under the direction of Dr. Ellen Hines (San Francisco State University) and created a high resolution land cover map and assessment of land cover classification accuracy. Phase 2 analyzed existing UTC, identified potential tree planting sites, developed a tree planting scenario, and estimated the value of existing and additional UTC.

Project Process

Phase 1 of the process started with baseline mapping to quantify land cover conducted by Dr. Ellen Hines and colleagues at San Francisco State University (Figure 1). This stage also utilized aerial images and GIS data. The second step consisted of an analysis of urban forest structure to determine the current extent and potential of the urban forest. This included quantifying the current tree cover as well as vacant planting sites. The third step involved quantifying, monetizing, and mapping annual ecosystem services and property value increases provided by the existing and future urban forest. The development of transfer functions and respective prices for each service the urban forest provides led to the mapping of service values. Asset values were calculated as the present value of the 100 year stream of future services from the existing and future urban forest at two discount rates. Data were normalized to compare results among cities of different sizes and to assess change. Examples of normalized metrics include percentage UTC, trees per capita, tree density (i.e., trees per acre) and stocking level (i.e., percentage of existing trees plus vacant sites filled with trees).

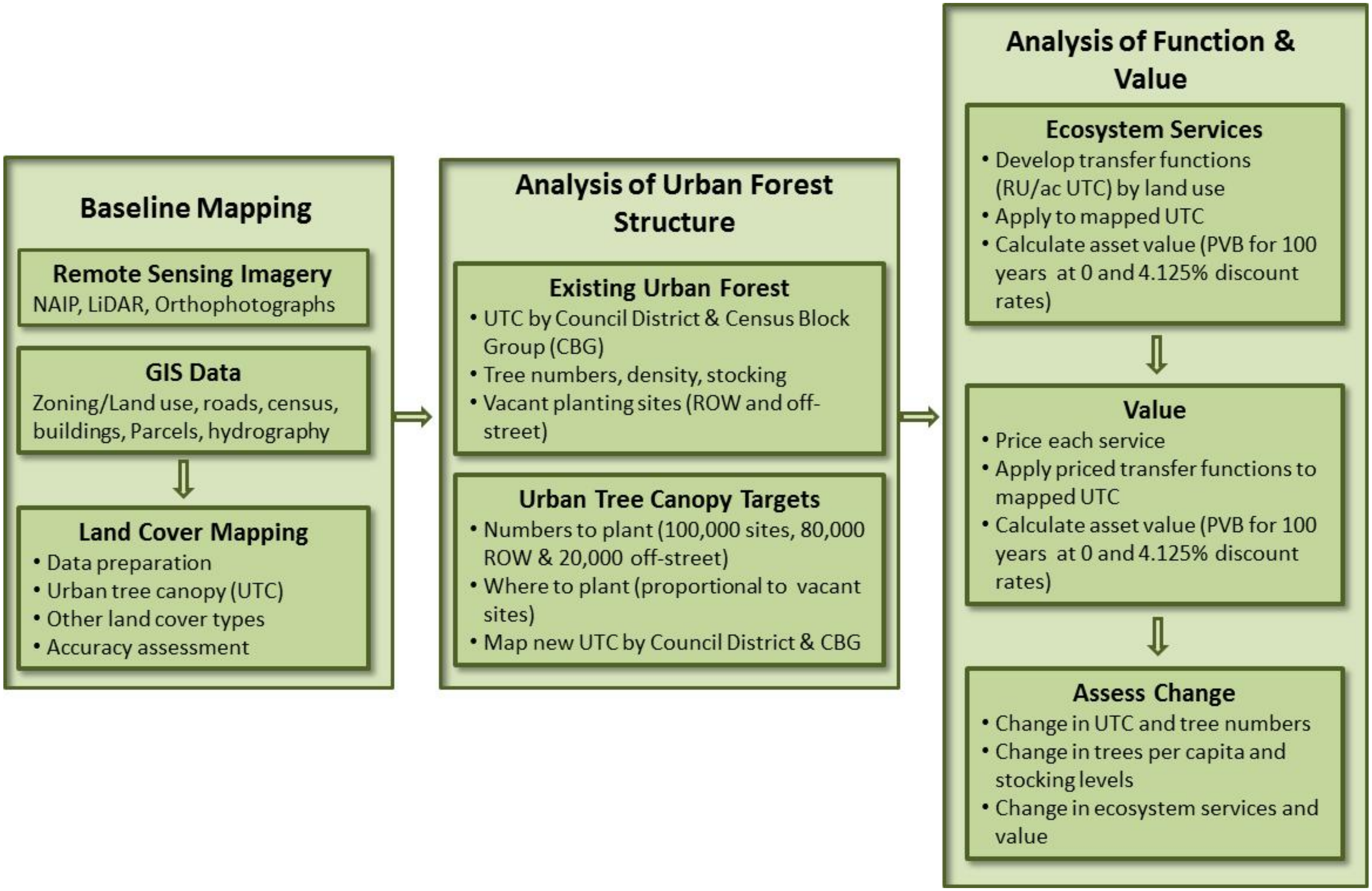


Figure 1. Project process overview.

Methodology

Study Site

Marin County is located northwest of the San Francisco Bay in California. It is about 430-ft above sea level and has a Mediterranean climate. Annual rainfall is about 38 inches over approximately 70 days. This precipitation mainly occurs in the winter months while the summer is rather dry. Average high temperature in the summer is about 81°F while the average low winter temperature is 40°F.

The study area comprised 77 square miles of urbanized land in Marin County, CA (Figure 2) and included 23 jurisdictions (Table 2) and about 8 acres of unincorporated area. The area of local communities ranged from 81 and 10,428 acres.

The region's total population is 252,000 people (www.city-data.com) with 219,000 people within the study area. Novato and San Rafael are the two largest jurisdictions in terms of area and population, with 47,000 and 54,000 residents, respectively. The population density within our study area averaged 4.4 per acre with the most densely populated community being Marin City CDP (10.2/ac).

Figure 2. Overview map of the study area.

Table 2. Population and area for each community within the study area.

Jurisdiction	Total Area (ac)	Project Area (ac)	Percentage	Population (Census 2010)
Alto CDP	80.5	80.5	100.0	711
Belvedere city	1,540.2	394.1	25.6	2,068
Black Point-Green Point CDP	1,726.8	1,377.9	79.8	1,024
Corte Madera town	2,819.1	1,626.0	57.7	8,993
Fairfax town	1,410.1	1,075.8	76.3	6,364
Kentfield CDP	1,945.9	1,587.3	81.6	6,404
Lagunitas-Forest Knolls CDP	2,717.8	205.0	7.5	10
Larkspur city	2,075.2	1,735.7	83.6	11,039
Lucas Valley-Marinwood CDP	3,664.6	1,168.6	31.9	4,380
Marin City CDP	343.5	217.4	63.3	2,228
Mill Valley city	3,101.9	2,657.2	85.7	12,602
Novato city	17,890.2	10,428.9	58.3	46,646
Ross town	995.9	815.6	81.9	2,168
San Anselmo town	1,713.2	1,653.4	96.5	11,882
San Geronimo CDP	964.9	165.6	17.2	217
San Rafael city	14,348.5	8,465.5	59.0	53,777
Santa Venetia CDP	2,354.9	622.1	26.4	3,659
Sausalito city	1,444.3	950.4	65.8	6,950
Sleepy Hollow CDP	1,911.5	1,027.7	53.8	1,160
Strawberry CDP	852.5	852.5	100.0	5,393
Tamalpais-Homestead Valley CDP	2,976.9	1,735.0	58.3	8,049
Tiburon town	8,435.1	2,095.7	24.8	8,931
Unincorporated	8,290.1	7,795.6	94.0	12,281
Woodacre CDP	1,149.7	647.4	56.3	922
Total	**84,753.1**	**49,380.7**	**58.3**	**217,858**

Software

- Image preparation tasks such as mosaicking and clipping were performed in ERDAS IMAGINE 2011.
- All vector processing and editing tasks were performed using ArcGIS 10.1.

Hardware

- Image processing and vector processing/editing were performed using a variety of Dell workstations with 6-12GB of RAM and dual/quad-core processors.

Image Data

The 2010 multispectral National Agricultural Imagery Program (NAIP) images as well as 2011 natural color aerial images provided by Marin County were used for this study. NAIP images had a resolution of 3-ft while the natural color images' resolution was 1-ft.

GIS Data

The 2010 Census block, block group, and tract data were obtained online (Table 3). Populations by census block and 'year structure built' by census tract were also compiled. Community data, including city data, were acquired from Marin County.

Buildings data GIS data were acquired from Marin County.

Population data were acquired from the 2010 census (downloaded November 2012). Some community population data as well as city and community area data were compiled for the study area using ArcGIS 10. Communities for which no population data could be directly found from census population data, GIS data layers of population by census block were used. Since community and block group GIS data boundaries did not align well, block groups were converted to centroids before these two GIS layers could be joined to result in population data by community.

Table 3. 2010 Census datasets used for the study.

2010 Census data	Feature type	Data source
Census block	polygon	ftp://ftp2.census.gov/geo/tiger/TIGER2010/TRACT/2010/ tl_2010_06041_tabblock10.zip
Census tract	polygon	ftp://ftp2.census.gov/geo/tiger/TIGER2010/TRACT/2010/ tl_2010_06041_tract10.zip
Census block groups	polygon	ftp://ftp2.census.gov/geo/tiger/TIGER2010/TRACT/2010/ tl_2010_06041_bg10.zip
Census block groups with population attributes	polygon	http://www.bayareacensus.ca.gov/small/ 2010_Pop_Block_County.xls

Zoning GIS data from Marin County were summarized from over 450 different zoning codes to nine zoning classes (Table 4). No zoning data were available for Fairfax and Novato. Land use data were manually assigned to census blocks based on aerial images.

Table 4. Description of zoning classes used for this study.

Zoning class	Code used	Definition	Distribution within study area	
			Area (acre)	%
Agriculture	Agri	agricultural land, including nurseries and orchards	2,917	5.9
Commercial	Comm	medium, large, and mixed commercial	1,770	3.6
Industrial	Ind	light, heavy, and mixed industrial	657	1.3
Mixed use	Mix	multiple land uses	162	0.3
Multi-Family Residential	MultiFam	medium, high, and mixed density residential	4,165	8.4
Open Space	OpenSpace	open space, excluding parks	4,711	9.5
Public-Quasi Public	PQP	roads/highways, water ways, schools, sports fields and golf courses, cemeteries, airports, parks, etc.	4,839	9.8
Single-Family Residential	SingleFam	low density residential	29,345	59.4
Small Commercial	SmComm	small commercial	820	1.7
Total			**49,385**	**100.0**

Definitions

- Remote Sensing Minimum mapping unit: 4 pixels (4 square meters)
- GIS Mapping units: census block group
- Reporting units: jurisdictions
- Parking lot: land area or facility for parking or storage of motor vehicles used for business, commerce, industry or personal use, with a lot size of 5,000 square feet or more of surface area

Land Cover Classification

Land Cover data were provided by San Francisco State University. Land cover classification was conducted using 2010 NAIP images. Land cover data are for 7 classes, buildings, other impervious, trees, shrubs, irrigated grass, non-irrigated grass and dry soil, and water.

Land Cover Classification Accuracy Assessment

The San Francisco State team conducted the land-cover classification accuracy assessment from 1,000 randomly placed points. Each point was independently assigned to a reference land-cover class based on the orthophotographs and NAIP imagery. The points were combined with the land-cover datasets, producing “reference” and “map” land-cover classifications for each point. This information was used to construct an error matrix in which the overall accuracy was computed along with the producer’s and consumer’s accuracies for each class.

Potential Tree Planting Sites

Tree Planting Scenario

A hypothetical tree planting scenario was developed to help identify the size and number of vacant sites for future planting. The scenario assumed that 50% of all PTPS were “planted” and it subdivided PTPS into two types; medium and large size sites. Medium sites were designated for polygons in irrigated grass with typical shade trees consisting of a 30-ft crown diameter at maturity (706.9-ft^2 crown projection area (CPA)). The second type of PTPS was for oaks and other large-stature native trees to be “planted” in non-irrigated grasslands. This type of site was for trees with a 50-ft crown diameter (1,963.5-ft^2 CPA) at maturity.

PTPS Adjustment Factors

There are many types of physical obstacles to tree planting that are not easily discernible from satellite imagery. Such obstacles include overhead power lines, underground sewer lines, vegetable gardens, sports fields, and pathways. Little research has documented the extent to which these obstacles limit planting in otherwise plantable sites (Wu et al. 2008). For a study conducted in San Jose (McPherson et al. 2013), a random sample of pervious polygons was field visited and evaluated for their suitability as tree planting locations. The collected data were used to determine an adjustment factor to be applied to calculations in Marin because similar limitations to tree plantings can be expected in both regions.

Out of all PTPS calculated, 211 random PTPS were field assessed for physical limitations. The field assessment involved noting the number and type of physical limitations to tree planting on field maps (NAIP images with 3.3-ft resolution and/or natural color 1-ft resolution), where each PTPS was drawn in the lab. Adjustment factors were calculated as the fraction of PTPS determined not plantable due to physical limitations. Adjustment factors of 0.83 for irrigated grass and 0.64 for bare soil/dry grass were calculated. Net PTPS were calculated as the product of adjustment factors and gross PTPS (formulas 3 and 4). We found that existing trees, other vegetation, and grey infrastructure (mainly sidewalks and buildings) were the most common physical limitations.

$$\#\ PTPS_{Grass} = \text{polygon area } (m^2) / 706.9\ (ft^2) \tag{1}$$

$$\#\ PTPS_{BSDV} = \text{polygon area } (m^2) / 1{,}963.5\ (ft^2) \tag{2}$$

$$\#\ \text{PTPS adjusted for physical limitations } (PTPS_{PL})\text{ Grass} = PTPS_{GL} * 0.83 \tag{3}$$

$$\#\ \text{PTPS adjusted for physical limitations } (PTPS_{PL})\text{ BSDV} = PTPS_{GL} * 0.64 \tag{4}$$

Parking Lot Demonstration

Parking lots are hot spots, sources of thermal pollution and contaminated runoff. Tree shade can mitigate urban heat island effects and reduce runoff through crown interception. It is difficult to quantify tree planting potential for parking lots using remote sensing because each lot is different. One case study lot is used here to demonstrate the potential for increasing UTC in parking lots throughout Marin County.

A demonstration parking lot was chosen to show the number and placement of trees needed to reach 50% UTC, a target set in the parking lot shade ordinances of several California communities. Two designs were developed, one for medium-size trees (30-ft crown diameter) and one for large-stature trees (50-ft crown diameter).

The parking lot is located at 1011 Andersen Dr. in San Rafael. It is in the 'industrial' zoning class surrounded by other parking lots, large buildings, and some open space (Figure 3). The first step of the design was the identification of the parking lot boundary. We used physical features discernible from aerial images. The boundary on the east end was determined to be the fence located at the transition of the parking lot to the adjacent street. On the north and west ends, the edge of the parking lot pavement was determined to be the boundary. South of the parking lot is a green strip about 30-ft wide on which a fence is located. This fence was identified as the south-end boundary.

After the parking lot area was determined, the needed canopy to reach 50% UTC was calculated by dividing the parking lot area by 2. The next step was to delineate the existing canopy within the parking lot and subtract its area from the needed canopy cover, resulting in the net canopy cover that new trees would have to provide. The net canopy cover was divided by 706.9-ft^2 and 1,963.5-ft^2, respectively, to result in the number of 30-ft and 50-ft crown diameter trees needed. This number was regarded as a minimum, since canopy overlap and tree canopy outside the parking lot boundary may require more trees than the theoretical number. To account for these "losses" in canopy and based on the placement criteria, the maximum number of trees possible were placed.

To avoid large canopy overlap and maximize shade, trees for the medium-tree design were placed at a density of one tree per 4 stalls whereas for the large-tree design, trees were placed at one tree per 8-10 stalls. Since concrete would have to be broken to incorporate the tree plantings, medium-sized trees were planted in 2-tree cutouts across two stalls in the center of the parking lot, converting four stalls into compact stalls. Along the perimeter, single trees were placed at a 1:4 ratio in diamond-shaped tree pits between two stalls. Single large trees were placed in the same cutout designs as two medium trees as they require larger soil volumes.

After tree center locations were identified in ArcGIS, 15-ft and 25-ft buffers were applied to depict tree crowns. To calculate percent potential UTC within the parking lot boundaries, any crown overlap from the canopy cover was excluded. The crown circles were merged together and any crown area located outside the parking lot boundary was also excluded. Findings are explained in the Results section.

Figure 3. Parking lot (red) used to demonstrate a tree planting design to reach 50% canopy cover.

Ecosystem Service Assessment

Urban trees provide ecosystem services by regulating climate and conserving building energy use, filtering pollutants from air and water, reducing soil erosion, and creating habitat for plants and animals. The natural beauty of trees plays an important role making communities attractive places to work and play. Urban forests produce shaded streets and trails that promote fitness from walking and biking. Planting and maintaining trees creates jobs and provides environmental education opportunities for youth.

This study evaluated ecosystem services values including energy, carbon, air quality, stormwater runoff, and property value effects for existing UTC and additional UTC. Benefits of carbon storage, carbon sequestration, air quality, and property values were based on transfer functions calculated for the San Francisco Bay Area State of the Urban Forest study (Simpson and McPherson 2007), while the energy effects were estimated based on laboratory analysis of tree-building distribution data within the study area.

Transfer function is a term used to describe the transfer of data for a particular "study site" to a "policy site" for which little or no data exist (Brookshire and Neill 1992, Downing and Ozuna Jr 1996). In this study, transfer functions are defined as field plot-based measures of a service (e.g., gallons of rainfall intercepted) per acre UTC (gal ac^{-1} UTC) that are aggregated and applied to a region by land use class. We express ecosystem services in terms of resource units (RUs), or engineering units, such as MWh, per unit UTC. Previous research found that this approach provided higher accuracy, greater precision, and improved spatial detail compared to services derived by land use class alone and applied as density values (e.g., gallons ac^{-1} residential land).

Different transfer function values reflect different stand structures and dynamics that influence the provision of ecosystem services. For instance, the carbon storage transfer function for an acre of UTC in an old residential neighborhood will be relatively high when the stand consists of closely spaced, mature oaks (*Quercus* spp.) and a lush understory. In contrast, the transfer function for an acre of UTC in a new residential area will be lower when the stand is characterized by juvenile pear (*Pyrus* spp.) trees with a sparse understory. Hence, the value of a transfer function reflects species composition and attributes of stand structure, such as tree and basal area densities. Species is important because of its influence on the tree's biomass and partitioning of carbon into roots, bole, branches, stems, and foliage. Stand attributes, such as the vertical layering of biomass in strata, tree density, and bole size also influence the amount of woody and foliar biomass per acre UTC.

The transfer function for each land use class is transferred to the UTC delineated for the corresponding land use. Using GIS capabilities, services are mapped and values are summed based on the amount of UTC in each land use class. These maps provide spatially explicit information on the distribution of ecosystem services for planning and management purposes.

Calculation Process

Calculating RUs for carbon, air quality, rainfall interception, and property values involved four steps. First, tree size/growth, climate, air pollutant concentrations and rainfall data to be used in benefit calculations for Santa Rosa (North Bay in Simpson and McPherson 2007) were compared for reference cities such as Modesto, Berkeley and San Francisco. Tree growth and geographic data from Modesto were found to be a better fit for Santa Rosa (Marin Co.) than data from San Francisco and Berkeley. For example, street trees in San Francisco were heavily pruned for bus clearance, which made for a poor match with fuller-crowned trees in Marin County. Information used in the analyses included climate, building types, benefit prices, air quality, and other environmental data. RUs per tree were calculated using tree data from reference city research in Modesto, CA (McPherson et al. 1999, McPherson and Simpson 2002) and described in the “Modesto Municipal Forest Resource Assessment.” RUs per tree and Crown Projection Area or UTC per tree were calculated as a function of species and size class from a stratified random sample of 22 species. About 30 to 50 trees of each species were measured in Modesto to establish relations between tree age, size, leaf area, and biomass (Peper et al. 2001). Trees were selected so as to represent as wide a range of sizes/ages as possible; 9 DBH size classes were used.

The second step was to convert RUs per tree to RUs per unit UTC for each species and size class represented:

$RUs/UTC_{j,k} = RUs/tree_{j,k} \div UTC/tree_{j,k}$,

where j for DBH size class 1 to 9, and k for species 1 to n, where n was 22 tree species for Modesto. In the third step, tree size dependence was removed by weighting RUs/UTC by the distribution of tree numbers by species and size class based on the Modesto tree inventory. In the final step, species dependence was removed and land use dependence was added based on

UTC by species and land use data derived from an earlier study (McPherson 1998). Crown widths (CW) reported for Sacramento were converted to UTC with the expression UTC = 2πCW.

Resource unit conversions removed explicit tree size and species dependence, and added land use dependence. Results were applied to the land cover/land use maps to calculate the values of ecosystem services across Marin.

Urban tree canopy was converted to estimates of tree numbers based on the average tree canopy diameter (D) of 16.4-ft (5m) found for Sacramento (McPherson 1998). Canopy diameter was converted to horizontal UTC by assuming a circular crown, where
UTC = πr^2 and r = D/2, so that average UTC = 211-ft^2 (19.6m^2).

Calculation of benefits from GIS polygons for each land use (m = 1 to 7) was a straightforward process. Benefits are the product of RUs per unit UTC, tree size class distribution (TDist) and UTC summed over size class (j = 1 to 9) and species (k = 1 to 22) for Modesto:

$$\text{Benefit}_m = \sum_{k=1}^{22}\left[\ \sum_{j=1}^{9}\left[\ \text{RUs/UTC}_{j,k} \times \text{TDist}_{j,k}\right] \times \text{UTC}_{k,m}\right]$$

The transfer functions and prices used to value each ecosystem service are shown in Table 5 and Table 6.

Table 5. Transfer functions (Resource Unit ac^{-1} UTC; in lbs. unless otherwise specified) for Marin County (North Bay) from the San Francisco Bay Area Report (Simpson and McPherson 2007).

Land Use	Heating (Mbtu)	Cooling (MWhs)	CO_2 net sequester (lbs)	CO_2 avoided (lbs)	Total CO_2 (lbs)	NO_2 (lbs)	O_3 (lbs)	PM_{10} (lbs)	SO_2 (lbs)	Net VOCs (lbs)	Interception (1,000 gal)	Property Value (ac/ac)
Residential Low	35.5	23.8	5,719.1	9,190.5	14,909.6	19.8	25.7	22.0	4.4	-19.0	79.7	1,696.3
Residential High	29.3	20.7	5,630.8	4,652.7	10,283.5	17.2	26.5	21.4	3.5	-11.9	91.1	2,050.9
Commercial / Industrial	37.3	10.5	5,595.0	8,084.7	13,679.7	18.8	22.8	19.4	2.2	-53.2	64.4	1,512.8
Institutional			9,834.7		9,834.7	15.2	28.3	21.6	2.7	-53.2	82.9	1,340.9
Open space			10,837.0		10,837.0	16.0	29.6	22.6	2.8	-56.6	89.5	1,338.4
Transportation			5,185.1		5,185.1	13.2	24.7	18.6	2.4	-26.0	67.9	889.4
Mix	26.0	16.6	6,878.4	6,385.1	13,263.6	18.4	26.3	21.7	3.7	-29.7	81.2	1,618.5

Table 6. Prices used to value ecosystem services in Marin County.

Benefit	Value
Heating ($/kbtu)	0.010
Cooling ($/kWhs)	0.186
CO_2 ($/lb)	0.005
NO_2 ($/lb)	0.005
O_3 ($/lb)	1.717
PM_{10} ($/lb)	1.717
SO_2 ($/lb)	0.652
Net VOCs ($/lb)	1.124
Interception ($/gal)	0.006
Property value ($/acre)	
Residential Low	14,935
Residential High	8,402
Commercial / Industrial	4,494
Institutional	4,323
Transportation	5,425
Mix	10,303

Atmospheric Carbon Dioxide Reduction

Calculating reduction in CO_2 emissions from power plants

Conserving energy in buildings can reduce carbon dioxide (CO_2) emissions from power plants. These avoided emissions were calculated as the product of energy savings for heating and cooling based on PG&E's electricity and natural gas CO_2 emission factors of 651 lbs. per MWh and 11.8 lbs. per MBtu, respectively (McPherson et al. 2010).

Calculating carbon storage

Sequestration, the net rate of CO_2 storage in above- and belowground biomass over the course of one growing season, was calculated by using tree height and DBH data with biomass equations (Pillsbury et al. 1998). Volume estimates were converted to green and dry-weight estimates (Markwardt 1930) and divided by 78% to incorporate root biomass. Dry-weight biomass was converted to carbon (50%) and these values were converted to CO_2. The amount of CO_2 sequestered each year is the change in storage that results from tree growth during a single growing season. The monetary value of sequestered and avoided CO_2 was $0.005/lb. based on average high and low estimates for emerging carbon trading markets.

Air Pollutants

Calculating reduction in air pollutant emissions

Reductions in building energy use also result in reduced emission of air pollutants from power plants and space-heating equipment. Volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO_2), both precursors of ozone (O_3) formation, as well as sulfur dioxide (SO_2) and particulate matter of <10 micron diameter (PM_{10}) were considered. Changes in average annual emissions and their monetary values were calculated in the same way as for CO_2, by using PG&E-specific emissions factors for electricity and heating fuels (U.S. Environmental Protection Agency 1998). The price of emissions savings were derived from models that calculate the marginal damage cost of different pollutants (Wang and Santini 1995). Emissions concentrations were obtained from US EPA (1997) and population estimates from the 2010 US Census (Donovan et al. 2013).

Calculating pollutant uptake by trees

Trees remove pollutants from the atmosphere. The modeling method we applied was developed by (Scott et al. 1998). It calculates hourly pollutant dry deposition per tree expressed as the product of deposition velocity ($V_d = 1/[R_a + R_b + R_c]$), pollutant concentration (C), canopy-projection area (CP), and a time step, where R_a, R_b, and R_c are aerodynamic, boundary layer, and stomatal resistances. Hourly deposition velocities for each pollutant were calculated during the growing season by using estimates for the resistances ($R_a + R_b + R_c$) for each hour throughout the year. Hourly concentrations for 2001 were selected as representative for modeling deposition based on a review of mean PM_{10} and O_3 concentrations for the years 1996 through 2004. The O_3, NO_2, and SO_2 data were from Oakland and PM_{10} from San Pablo (Raciti et al. 2006b). Hourly air temperature and wind speed data were obtained from Berkeley (Raciti et al. 2006b). To set a value for pollutant uptake by trees, we used the procedure described above for emissions reductions. The monetary value for NO_2 was also used for O_3.

Estimating BVOC emissions from trees

Annual emissions for biogenic volatile organic compounds (BVOCs) were estimated for each tree species by using the algorithms of Guenther et al. (1991, 1993). Annual emissions were simulated during the growing season. The emission of carbon as isoprene was expressed as a product of the base emission rate (micrograms of carbon per gram of dry foliar biomass per hour), and was then adjusted for sunlight, temperature, and the amount of dry, foliar biomass present in the tree. Monoterpene emissions were estimated by using a base emission rate adjusted for temperature. The base emission rates were established from values reported in the literature (Benjamin and Winer 1998). Hourly emissions were summed to get monthly and annual emissions.

Annual dry foliar biomass was derived from field data. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Hourly air temperature and solar radiation data were used as model inputs.

Calculating net air quality benefits

Net air quality benefits were calculated by subtracting the costs associated with BVOC emissions from benefits owing to pollutant uptake and avoided power plant emissions. The O_3 reduction benefit from lowering summertime air temperatures, thereby reducing hydrocarbon emissions from anthropogenic and biogenic sources, were estimated as a function of canopy cover following McPherson and Simpson (1999). They used peak summer air temperature reductions of 0.2°F for each percentage of increase in canopy cover. Hourly changes in air temperature were calculated by reducing this peak air temperature at every hour based on hourly maximum and minimum temperatures for that day, as well as maximum and minimum values of total global solar radiation for the year. However, this analysis does not incorporate the effects of lower summer air temperatures on O_3 formation rates owing to atmospheric processes. The value of ecosystem services for air quality were monetized using models that calculated the marginal cost of controlling different pollutants to meet air quality standards (Wang and Santini 1995). All air pollutant prices are shown in Table 6.

Rainfall Interception

Urban trees can reduce the amount of runoff and pollutant loading in receiving waters by intercepting and storing rainfall on leaves and branch surfaces. Root growth and decomposition can also increase the capacity and rate of soil infiltration by rainfall and reduce overland flow (Bartens et al. 2008). Studies on urban forest impacts on stormwater reported an annual runoff reduction of 2 to 7% (Xiao et al. 1998a).

Estimating rainfall interception by tree canopies

A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 2000). The interception model accounted for water captured by the tree, as well as throughfall and stem flow. Intercepted water is stored temporarily on canopy leaf and bark surfaces. Rainwater drips from leaf surfaces, flows down the stem surface to the ground or evaporates. Tree-canopy parameters that affect interception include species, leaf and stem surface areas, shade coefficients (visual density of the crown), foliation periods, and tree dimensions (e.g., tree height, crown height, crown diameter, and DBH). Tree-height data were used to estimate wind speed at different heights above the ground and resulting rates of evaporation.

The volume of water stored in the tree crown was calculated from crown-projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), and the depth of water captured by the canopy surface. Gap fractions, foliation periods, and tree surface saturation storage capacity influence the amount of projected throughfall. Tree surface saturation was 0.04in for all trees. Hourly meteorological and rainfall data for 2002 from the CIMIS (California Irrigation Management Information System) Santa Rosa Station (ID #83; latitude 38°24' N, longitude 122°48' W) were used for this simulation. Annual precipitation during 2001 was 16.7 in (424.4 mm). Storm events less than 0.1 in were assumed to not produce runoff and were removed from the analysis. More complete descriptions of the interception model can be found in Xiao et al. (1998b).

Calculating water quality protection and flood control benefit

The benefit of runoff reduction was estimated using costs associated with collection, conveyance, and treatment of stormwater from sewer service fees, a conservative proxy for a desired level of service. Interception was priced based on mean fees for San Francisco, Berkeley, and Modesto (Simpson and McPherson 2007). The price of $0.006 per gallon is comparable to the average price for stormwater runoff reduction ($0.01/gallon) reported in similar studies (McPherson et al. 2005).

Property Value

Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, wildlife habitat, shade that increases human comfort, sense of place, and well-being are services that are difficult to price. However, the value of some of these benefits may be captured in the property values of the land on which trees stand. To estimate the value of these “other” benefits, we applied results of research that compared differences in sales prices of houses to statistically quantify the difference associated with trees. All else being equal, the difference in sales price reflects the willingness of buyers to pay for the benefits and costs associated with trees. Limitations to this approach include difficulty determining the value of individual trees on a property, the need to extrapolate results from studies done years ago in the East and South to this region, and the need to extrapolate results from front-yard trees on residential properties to trees in other locations (e.g., back yards, streets, parks, and non-residential land).

Anderson and Cordell (1988) surveyed 844 single-family residences in Athens, GA, and found that each large front-yard tree was associated with a 0.88% increase in the average home sales price. This percentage of sales price was utilized as an indicator of the additional value a resident in Marin County would gain from selling a home with a large tree. The sales price of residential properties varied widely by location within Marin County, but the median was $648,333 (Simpson and McPherson 2007). Therefore, the value of a large tree that added 0.88% to the sales price of such a home was $5,705. To estimate annual benefits, the total added value was divided by the leaf surface area of a mature shade tree ($5,705/3,348-ft^2) to yield the base value of $0.17/ft^2 of leaf surface area. This value was multiplied by the amount of leaf surface area added to the tree during one year of growth.

To adapt and apply the base value to Marin’s urban forest, a land use reduction factor was applied because the value of trees located in back yards and non-residential property will have less impact on sales price and other intangible benefits compared to front-yard trees (Richards et al. 1984). Lacking specific research findings and wanting to be conservative, it was assumed that single family residential UTC had less impact of a front-yard tree. Overall, the reduction factor of 0.834 was applied based on tree distributions among land uses (Simpson and McPherson 2007).

Energy savings

Tree-Building distribution for ecosystem service calculations

One of the most tangible effects of trees is on home energy costs for cooling and heating due to shading on buildings (Simpson and McPherson 1998, Simpson 2002). The shading effect of a tree is dependent on its size and location as well as growth habit. For example, evergreen trees provide shade year-round whereas deciduous trees do not. This, however, might not necessarily be a desired scenario for colder regions as evergreen trees would reduce solar energy from reaching a building in the winter. The resulting heating costs from that scenario might be higher than they would be with a deciduous tree growing at the same location. Thus, the growth habit of a tree is very important when trying to optimize energy savings.

To evaluate the effect of different tree sizes and locations on energy consumption, savings templates can be consulted. These templates give information on energy effects of a tree based on its location relative to residential buildings by tree species and building vintage classes. Thus, tree planting efforts can be prioritized to optimize future canopy's energy effects using these templates, as well as PTPS information.

Data

The analysis was conducted using 2011 high-resolution (0.3m) natural color aerial images as well as a building GIS layer acquired from the County of Marin. Building GIS data were verified and corrected if necessary to assure polygons aligned with the aerial image. Images from the 2010 multispectral National Agricultural Imagery Program (NAIP), as well as Google street view, were consulted when needed to help discern trees and other pervious land cover classes.

Buildings constructed pre-1950, 1950 to 1980, and post-1980 generally differed in terms of floor area, floor type, glazed area, insulation (R value), and number of stories (Table 7). Since these parameters affect the energy use of a building, analyses and results are separated by vintage class.

Table 7. Descriptors of buildings constructed pre-1950, 1950 to 1980, and post-1980.

Descriptors	pre-1950	1950 to 1980	post-1980
Floor area (sqft)	975	1,080	2,070
Glazed area (sqft)	177	196	263
R values, wall (hr*ft^2-°F/BTU)	7	7	13
Stories	1	1	2

Sampling design

Average cooling and heating effects per tree were compiled from data collected on 125 random sample plots across the residential zoning class. Points were placed on the map at random using ArcGIS 10 and functioned as the center point for a 100m-diameter circular sampling plot. To get a full picture of tree-building distributions the sampling unit was extended to include 18.3m around buildings that were at least partially contained in the sample plot (Figure 4 and Figure 5).

Existing trees

For each tree within the sampling extent the crown boundary was delineated (Figure 4) and the tree size class determined. To account for different growth habits of trees in our analysis, three model tree species were chosen; a large, broadleaf deciduous tree (*Platanus hybrida*, plane tree), a large, broadleaf evergreen tree (*Magnolia grandiflora*, Southern magnolia), and a large conifer (*Pinus radiata*, Monterey pine). For areas with connecting canopies, e.g. wooded lots, a medium tree (9.1m crown diameter) was used to divide the area into single trees. Circles representing a 9.1m tree were packed as tightly as possible within the wooded area. For all polygons the centroid was then determined which was assumed to be the location of the trunk.

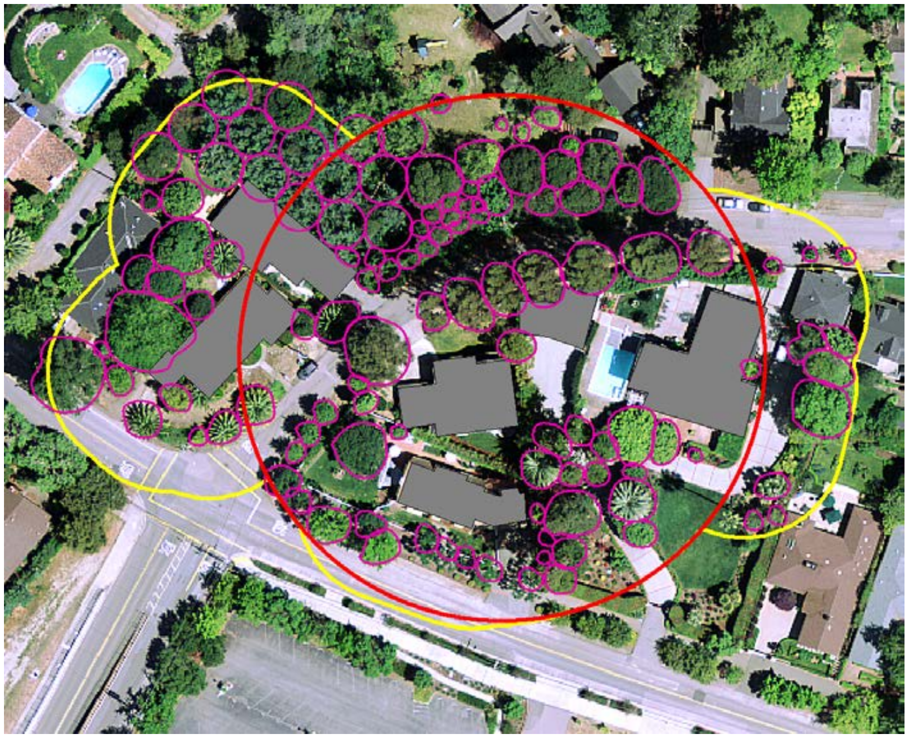


Figure 4. Sampling plot (328-ft-diameter) shown in red; delineated canopy of trees, pink, within the sample plot; as well as trees within 60-ft of buildings that are partially within the plot (grey); sampling extent shown in yellow.

<u>Potential Tree Planting Sites (PTPS)</u>

After the existing tree canopy was delineated, potential tree planting sites (PTPS) were identified for all pervious areas including; irrigated grass, dry grass, and bare soil (Figure 5). First, large tree locations were identified (15.3m crown diameter), then medium (9.1m), then small (4.6m). A number of criteria had to be fulfilled for potential tree planting site placement:

a. A minimum of $9.3m^2$ of soil was required for large trees, $3m^2$ for medium trees, and $1.5m^2$ for small trees.
b. PTPS were placed with minimal overlap to buildings, other canopy, and areas outside the sampling area (max. ca. 2m).
c. A minimum distance from tree center to surrounding structure was assured:
    i. 0.6m to surrounding impervious pavement
    ii. 5m to surrounding buildings for large trees, 3m for medium trees, no minimum for small trees.
    iii. Tree canopy overlap was no more than ca. 2m for medium and large trees. No overlap for small trees.
d. No large or medium trees were placed within 5m of an intersection to avoid obstructed visibility for vehicles.

e. No medium or large trees were placed under power lines or other infrastructure that would impede tree growth in the long term.
f. No small trees were placed if they would be surrounded closely by existing medium or large trees if these small trees would receive virtually no light which then would limit their growth and survival.

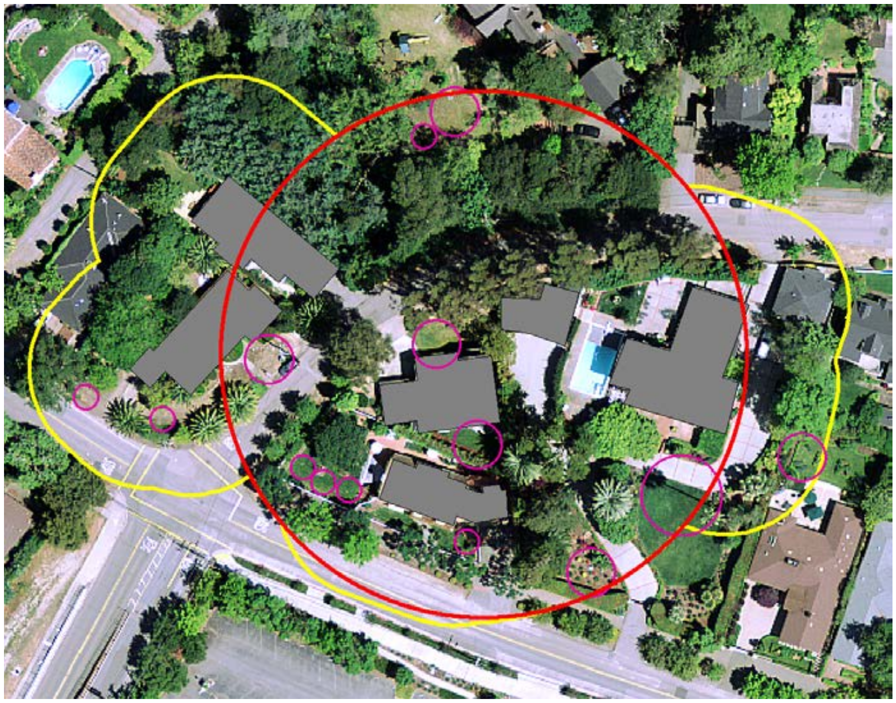


Figure 5. Sampling plots (328ft-diameter) shown in red, PTPS representing large, medium and small trees, pink, within the sampling plot as well as trees within 60ft of buildings that are partially within the sampling plot (grey), sampling extent shown in yellow.

Because the lookup tables (Simpson 2002) used to compile energy savings are based on nine trunk diameter at breast height (DBH) classes, the crown diameter of the existing trees and PTPS from our sample analysis had to be converted to DBH. We used existing tree growth data (DBH and canopy projection) for the Bay Area region (Berkeley) for plane tree (*Platanus hybrida,* PLAC), Southern magnolia (*Magnolia grandiflora*, MAGR), and Monterey pine (*Pinus radiata*, PIRA) to include the different growth habits of trees in our analysis. The tree growth data were used to develop linear models:

a. Deciduous broadleaf: *Platanus hybrida* (PLAC), plane tree
→ DBH (cm)= 0.281504*Crown Projection (m^2) + 5.484907 (R^2=0.99)

b. Evergreen broadleaf: *Magnolia grandiflora* (MAGR), Southern magnolia
→ DBH (cm)= 0.449436617*Crown Projection (m^2)+5.099417809 (R^2=0.99)

c. Evergreen needleleaf: *Pinus radiata* (PIRA), Monterey pine
→ DBH (cm)=0.408288698* Crown Projection (m^2) + 13.3314855 (R^2=0.97)
This model showed a very poor fit for smaller trees. Thus, for trees less than 25cm in DBH, the following model was used:
→ DBH (cm)= 0.865327722*Crown Projection (m^2) -0.009649527 (R^2=0.98)

Once DBH values for trees and PTPS were calculated, tree records were divided into the nine DBH classes. Then, energy savings for cooling and heating were compiled for each tree and PTPS using Simpson's lookup tables (2002). These energy savings include a location effect if the tree or PTPS was within 60-ft of the building, as well as a climate effect which is not specific to tree location. For trees and PTPS outside 60-ft, only climate effects were complied.

Tree and PTPS-Building distribution
Building centroids as well as tree-building relationships were assessed using ArcGIS 10. The azimuth of existing trees and PTPS was calculated to building centroids, while their distance was calculated to building walls or building polygon boundaries. Four distance classes were used; class 1 (<6.1m), 2 (6.1-12.2m), 3 (12.2-18.3m) and 4 (>18.3m). In addition, the zoning class was determined for each tree center. This was done because, even though the sample plot center was located in a residential area, trees and PTPS within the gross sampling units might be located in an adjacent zoning class.

Energy effects
Energy effects of trees depend on size and species. However, tree species cannot be discerned from aerial images. To include the different growth habits of trees in our analysis, three model tree species were chosen as mentioned previously. For each tree and PTPS, energy savings using Simpson's lookup tables (2002) based on data from Santa Rosa (McPherson et al. 2008) were compiled for the three model tree species. Trees within 60-ft of a building provide shade benefits that are location specific, while trees outside the 60-ft limit provide a climate benefit that is not location specific. Energy savings were compiled on a per tree basis as well as on a unit canopy basis. Since the effect of trees on buildings is not linear due to overlapping canopies, an adjustment factor of 0.95 was applied to the energy effects of every tree that shared a building with at least one other tree (Simpson and McPherson 1998).

Tree-Building distribution for energy calculations
A total of 10,950 trees and 2,507 PTPS were identified within the 125 sampling plots which encompassed a total area of 388 acres (0.8% of the study area). Despite the fact that sample plot center points were placed into the residential zoning class, buildings as well as trees and PTPS surrounding the buildings were not solely residential (Table 8).

Table 8. Zoning distribution of existing trees, PTPS, and buildings from 125 sample plots.

Zoning class	Existing Trees	PTPS	Buildings
Agri	6	5	-
Comm	71	14	-
MultiFam	1,655	406	108
OpenSpace	177	73	-
PQP	264	43	-
SingleFam	8,621	1,927	604
SmallCom	156	39	13
Grand Total	**10,950**	**2,507**	**725**

The number of trees sampled in communities that were part of this analysis ranged from 28 to 2,449 (Table 9). The fewest sample trees were in Strawberry CDP and the most were in Novato City. Out of 725 buildings included in the sample, one was located in Strawberry CDP, while Novato and San Rafael had 190 and 104, respectively. The latter two also showed the greatest area included in the sample with 98 and 55 acres, which equates to about 1% of their land area. The overall average number of trees per buildings varied between 9 in Corte Madera town and 34 in Sleepy Hollow CDP, while the average number of PTPS was between 0.2 in Sausalito city and 18 in Black Point-Green Point CDP.

Table 9. Raw distribution of trees, PTPS, and buildings by jurisdiction*.

Jurisdiction	Area included in the study (km^2)	Area sampled (km^2)	Proportion of jurisdiction area sampled	# of trees	# of buildings	# of PTPS	Overall avg # trees per building	Overall avg # PTPS per buildings
Alto CDP	0.3	0.0	0.0					
Belvedere city	1.6	0.0	0.0					
Black Point-Green Point CDP	5.6	0.0	0.4	110	5	92	22.0	18.4
Corte Madera town	6.6	0.1	1.0	419	47	64	8.9	1.4
Fairfax town	4.4	0.1	1.4	628	37	68	17.0	1.8
Kentfield CDP	6.4	0.1	0.8	751	38	84	19.8	2.2
Lagunitas-Forest Knolls CDP	0.8	0.0	0.0					
Larkspur city	7.0	0.0	0.2	123	7	29	17.6	4.1
Lucas Valley-Marinwood CDP	4.7	0.0	0.3	183	13	60	14.1	4.6
Marin City CDP	0.9	0.0	1.7	112	9	30	12.4	3.3
Mill Valley city	10.8	0.1	1.0	693	54	216	12.8	4.0
Novato city	42.2	0.4	0.9	2,449	190	703	12.9	3.7
Ross town	3.3	0.0	0.8	398	5	39	79.6	7.8
San Anselmo town	6.7	0.1	1.8	1,003	75	192	13.4	2.6
San Geronimo CDP	0.7	0.0	0.0					
San Rafael city	34.3	0.2	0.6	1,477	104	288	14.2	2.8
Santa Venetia CDP	2.5	0.0	0.0					
Sausalito city	3.8	0.0	0.4	172	14	3	12.3	0.2
Sleepy Hollow CDP	4.2	0.0	1.2	572	17	108	33.6	6.4
Strawberry CDP	3.5	0.0	0.0	28	1	14	28.0	14.0
Tamalpais-Homestead Valley CDP	7.0	0.1	1.1	590	47	143	12.6	3.0
Tiburon town	8.5	0.0	0.5	512	33	98	15.5	3.0
Unincorporated	31.6	0.3	0.9	730	29	276	25.2	9.5
Woodacre CDP	2.6	0.0	0.0					
Grand Total	**200.0**	**1.6**	**0.8**	**10,950**	**725**	**2,507**	**15.1**	**3.5**

*each tree sampled was only included once.

On average, residential buildings sampled in Marin County had 16.1 trees and 4.1 PTPS within 60-ft, while the average tree and PTPS shades 1.1 and 1.0 building, respectively (Table 10). Twenty-five percent of trees were found within 20-ft of the building, 23% between 20 and 40-ft, and 19% between 40 and 60-ft. Thirty four percent of the trees were beyond 60-ft, providing a climate effect only (Table 11). A similar trend can be seen for PTPS; 26% were found within 20-ft, 20% within 20 to 40-ft and 20% within 40 to 60-ft (Table 12). Thirty-six percent of PTPS provide a climate effect only (data not shown).

Table 10. Mean and standard error of trees and PTPS per building and vice versa for 125 sample plots*.

	Overall average	Single-family residential#	Multi-family residential#	Other
Avg # trees per bld	16.1 (0.3)	16.0 (0.3)	16.7 (1.0)	15.9 (3.0)
Avg # bld per tree	1.1 (0.0)	1.1 (0.0)	1.0 (0.0)	0.5 (0.0)
avg # PTPS per bld	4.1 (0.1)	4.0 (0.1)	4.0 (0.5)	5.8 (1.9)
Avg # bld per PTPS	1.0 (0.0)	1.0 (0.0)	0.7 (0.0)	0.6 (0.0)

*Includes 10,950 trees. Trees which provided shade to multiple buildings were included multiple times.
[#] see table 2 for definitions

Because sample plots were located based on their center points, some trees and PTPS ended up being located outside the residential zoning class or surrounding non-residential buildings. The exclusion of those trees and PTPS resulted in a sample of 10,206 trees and 2,332 PTPS (Table 11 and Table 12).

Table 11. Numbers of trees within the residential zoning class outside and within 60-ft of residential buildings*.

Vintage/Azimuth	Distance Class				Grand Total
	1 (<20ft)	2 (20-40ft)	3 (40-60ft)	4 (>60ft)	
Pre-1950 Buildings					
W	36	23	22		81
SW	24	25	33		82
SE	26	20	27		73
S	31	34	28		93
NW	26	23	26		75
NE	29	26	31		86
N	27	20	22		69
E	26	22	26		74
Clim. effect				420	420
Total	**225**	**193**	**215**	**420**	**1,053**
1950-80 Buildings					
W	286	263	210		759
SW	312	316	221		849
SE	257	264	217		738
S	286	273	212		771
NW	301	235	219		755
NE	262	270	219		751
N	303	295	244		842
E	289	233	201		723
Clim. effect				2,757	2,757
Total	**2,296**	**2,149**	**1,743**	**2757**	**8,945**
Post-1980 Buildings					
W	8	4	2		14
SW	5	6	6		17
SE	11	3	3		17
S	16	8	4		28
NW	11	7	3		21
NE	14	8	1		23
N	14	6	3		23
E	9	3	1		13
Clim. effect				52	52
Total	**88**	**45**	**23**	**52**	**208**
Grand Total	**2,609**	**2,387**	**1,981**	**3,229**	**10,206**

*From 10,950 trees within the sample. Trees that provided shade to multiple buildings were included only once based on the closest building.

Table 12. Numbers of PTPS within the residential zoning class outside and within 60-ft of residential buildings*.

Vintage/Azimuth	Distance Class				Grand Total
	1 (<20ft)	2 (20-40ft)	3 (40-60ft)	4 (>60ft)	
Pre-1950 Buildings					
E	5	5	4		14
N	1	1	1		3
NE	1	4	1		6
NW	3	2	1		6
S	1	1			2
SE	3	4	3		10
SW	4	1	2		7
W	1	2	2		5
Clim. effect				46	46
Total	**19**	**20**	**14**	**46**	**99**
1950-80 Buildings					
E	63	64	57		184
N	69	48	59		176
NE	71	58	68		197
NW	56	55	40		151
S	75	55	47		177
SE	63	52	41		156
SW	86	55	60		201
W	50	55	48		153
Clim. effect				727	727
Total	**533**	**442**	**420**	**727**	**2,122**
Post-1980 Buildings					
E	5	3	3		11
N	4	1			5
NE	4	1	4		9
NW	7				7
S	4	3	2		9
SE	3	1	4		8
SW	6	1			7
W	3	1	1		5
Clim. effect				50	50
Total	**36**	**11**	**14**	**50**	**111**
Grand Total	**588**	**473**	**448**	**823**	**2,332**

*From 2,507 PTPS within the sample. PTPS which are within 60-ft of multiple buildings were included only once based on the closest building.

The largest number of trees per building (Table 13) was for buildings built between 1950 and 80 (16.3 trees), followed by buildings built pre-1950 (15.2 trees), and those built post-1980 (8.8 trees). The highest number of PTPS was found in vintage class 1950 to 1980 (4.2 PTPS), followed by post-1980 with 3.6, and pre-1950 with 3.1 PTPS per buildings. These results show that despite the large number of existing trees, there is still potential to increase tree canopy cover.

Table 13. Tree- and PTPS-building distribution based on 125 sample plots divided by building vintages*.

Vintage	Avg # trees per bld	Avg # bld per tree	Avg # PTPS per bld	Avg # bld per PTPS
<1950	15.2 (1.1)	1.0 (0.0)	3.1 (0.9)	0.8 (0.1)
50-80	16.3 (0.3)	1.1 (0.0)	4.2 (0.1)	0.9 (0.0)
>1980	8.8 (0.7)	1.7 (0.1)	3.6 (0.4)	1.2 (0.1)

*Includes 10,950 trees and 2,507 PTPS. Trees and PTPS which are within 60-ft of multiple buildings were included multiple times.

<u>Transfer functions</u>

Based on the distribution of trees and PTPS around buildings, transfer functions (resource units per unit canopy) were compiled. The transfer functions from the sample analysis were then used to extrapolate energy savings for the entire urbanized portion of Marin County using land cover data developed by the team at San Francisco State University.

The focus was on residential structures, thus only trees, PTPS, and buildings located in the residential zoning class were included. To compile the transfer functions, Simpson's (2002) lookup tables were used for single-family residential buildings based on data from Santa Rosa (McPherson et al. 2008). Since multi-family residential buildings share walls and roofs, the transfer functions had to be adjusted. Based on Maco et al (2005) the location-specific as well as the climate effect of trees within 60-ft of multi-family residential buildings also had to be adjusted. Since the majority of multi-family residential buildings within our sample has less than five units, an average potential shade adjustment factor of 0.74 was used as well as a potential climate adjustment factor of 0.8 (Maco et al. 2005). The distribution of large broadleaf evergreen (LBE), large conifers, and large broadleaf deciduous (LBD) trees in San Francisco, which is assumed to be similar to Marin County, shows that out of these tree growth habits, 46.5% are LBE, 14.7% are conifers, and 38.8% are LBD. Transfer functions were calculated from RU's for the three model tree species using this distribution.

The results for transfer functions show that trees in urbanized Marin County provide on average 35 MBtu in heating savings and 24 MWh in cooling savings annually per acre UTC across all zoning classes. This is an equivalent of $337 for heating and $4,480 for cooling per year per acre UTC. Focusing on residential zoning classes only (Table 14), average savings per acre canopy are 38 and 35 MBtu for heating and 25 and 22 MWh for cooling for single-family and multi-family residential buildings, respectively. This equates to $362 and $330 in heating savings and $4,669 and $4,027 in cooling savings per year per acre UTC. The results for heating savings agree with findings by Simpson and McPherson (2007) who found 34.4 MBtu/acre UTC for the North San Francisco Bay area. However, the results for cooling are higher than the 14.5 MWh per acre UTC found by Simpson and McPherson. Trees included in Simpson and McPherson's study were street and park trees only. Trees expected to have the greatest cooling effect, those within 60-ft of buildings, were not included in their dataset and analysis, which may explain why the cooling savings reported here are more than found in their study. In addition, this study may have more thoroughly accounted for cooling effects of trees that shaded multiple buildings.

Table 14. Transfer functions (Resource Unit/ ac UTC) for Marin County from our sample analysis*.

Zoning class	Existing trees	Heating (MBtu/ acre UTC)	Heating ($/ acre UTC)	Cooling (MWh/ acre UTC)	Cooling ($/ acre UTC)
Single Family Bld	9,467	37.9	361.74	25.1	4,668.97
Multi Family Bld	1,707	34.6	329.78	21.7	4,026.91
Other residential trees#	3,229	24.3	232.06	18.9	3,508.64

*Includes 10,950 trees. Trees which provided shade to multiple buildings were included multiple times.
Includes trees within the residential zoning class that did not shade a residential building and thus provide a climate effect only.

Templates

Energy effect templates were compiled for a medium sized (30-ft crown diameter) model tree using the full range of distance, azimuth, and vintage classes. These templates help evaluate tree planting scenarios for their energy effects.

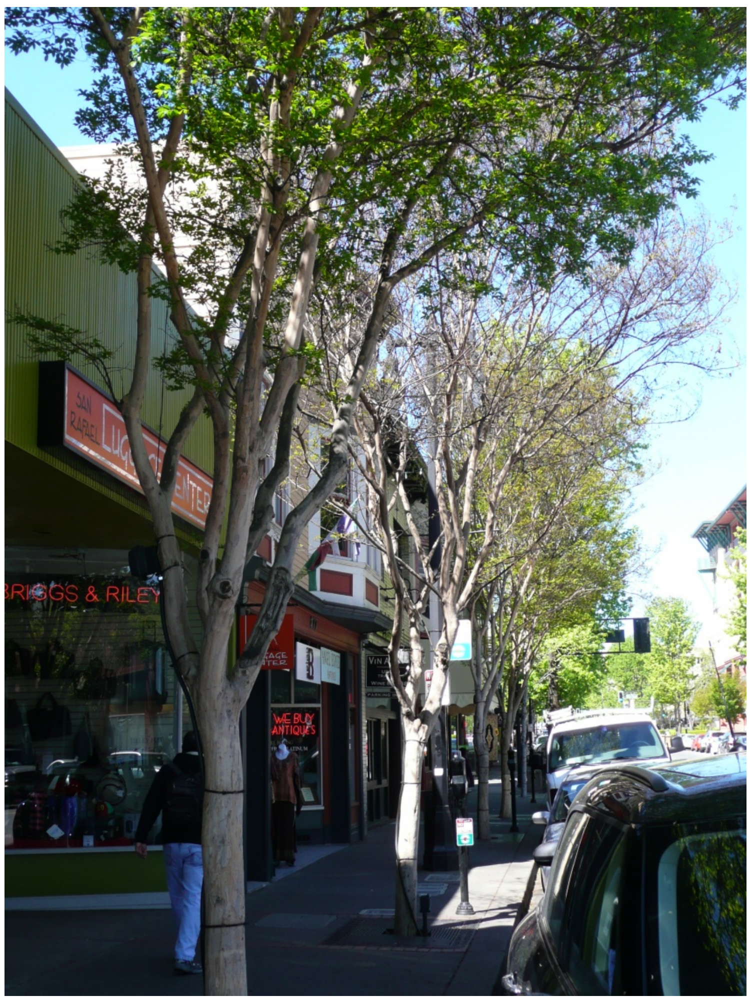
The compilation of energy templates for each of the three tree types and vintage classes showed that a medium (30-ft crown diameter) tree at maturity would provide annual benefits of 199 to 824 kWh ($36.99 to 153.18) for cooling and -689.1 and 243.9 kBtu ($-6.57 to $2.33) for heating per acre UTC. The negative effects on heating are due to an increased demand for heating due to the obstruction of solar energy reaching a building by trees. This adverse effect is much less than the positive effect that the same trees have on cooling energy use.

It is recommended to consult the energy templates (Table 35 to Table 37) when prioritizing tree planting efforts for energy savings. For example, the highest energy savings for cooling, 824 kWh, would be accomplished by planting a broadleaf evergreen within 20-ft and on the west side of a pre-1950 building.

As an example, assume 1,000 trees were planted and one third are conifers that only provide a climate effect (distance class 4), one third are large broadleaf evergreens on the west side, and one third are large, broadleaf deciduous on the east side, both within 20-40-ft of residential buildings (distance class 2). One might decide to plant them around buildings built post-1980 since, on average, less trees currently shade buildings from that vintage class. By the time the trees reach 30-ft in crown diameter, the total annual savings would be $49,043.52 (Table 15); $49,926.42 for cooling savings, but $882.90 in additional heating costs due to the obstruction of solar radiation on buildings in the winter.

Table 15. Annual energy effects of 1,000 trees; post-1980 vintage.

Vintage	Tree Number	Cooling (kWh/tree)	Cooling ($/tree)	Heating (kBtu/tree)	Heating ($/tree)
Pinus radiata, clim effect	333	201	37.37	108.8	1.04
Magnolia grandiflora, west, dist 2	333	437	81.24	53.8	0.51
Platanus hybrida, east, dist 2	334	168	31.23	-440.2	-4.20
Total for 1,000-tree planting	1,000	268,556	49,926.42	-92,881	-882.90



Results and Discussion

Land use and cover

The study area covered 49,391 acres with 70% residential land; 59% single family and 8% multi-family residential (Table 16 and Table 17). Open space and public/quasi-public land accounted for 10% of the study area, agriculture 6%, commercial 5%, and industrial or mixed-use land 2%. Novato (21%) and San Rafael City (17%) were the largest jurisdictions, while the smallest jurisdictions were Alto (0.2%) and San Geronimo CDP (0.3%); (Table 16).

Urban tree canopy covered 36.3% of the study area, while 18.4% was classified as other impervious, such as parking lots and driveways. This was followed by irrigated grass (13.7%), bare soil and dry vegetation (11.5%), buildings (10%), shrubs (6.4%) and water (3.7%); (Table 17).

Urban tree cover was highest in Ross (67%) and lowest in Lagunitas-Forest Knolls CDP (19.8%); (Figure 6). The highest percentage of impervious surfaces (buildings, roads, and water) was in Alto CDP (52%) and the lowest in Black Point-Green Point CDP (14%) and Woodacre CDP (14%) and Lagunitas-Forest Knolls CDP (12%); (Table 18). The highest percentage of pervious areas not already occupied by trees, only shrubs, grass, and bare soil, was in Lagunitas-Forest Knolls CDP (68%) showing a large potential for new tree plantings, while Sausalito CDP (18%), Kentfield CDP (14%), and Ross town (13%) had comparably low pervious surfaces.

Appendix II shows examples of UTC by census block group. Detailed tables like this can be found for all of the datasets in digital form submitted with this report.

Table 16. Land use (acre) by jurisdiction.

Jurisdiction	Agri	Com	Ind	Mix	MultiFam	OpenSpace	PQP	SingleFam	SmallCom	Total	Percentage
Alto CDP	1.0	11.9	0.0	0.0	3.9	5.0	0.0	58.7	0.0	**80.5**	**0.2**
Belvedere city	0.0	0.0	0.0	0.0	18.2	11.5	5.7	353.8	4.9	**394.1**	**0.8**
Black Point-Green Point CDP	146.3	0.0	0.0	0.0	2.9	141.0	35.2	1,036.4	16.2	**1,377.9**	**2.8**
Corte Madera town	0.0	82.4	21.8	0.0	129.5	16.2	353.4	917.4	105.2	**1,626.0**	**3.3**
Fairfax town	0.0	10.2	0.0	0.0	0.4	159.4	28.7	868.3	8.7	**1,075.8**	**2.2**
Kentfield CDP	0.0	10.0	0.0	0.0	49.3	97.3	84.3	1,346.5	0.1	**1,587.3**	**3.2**
Lagunitas-Forest Knolls CDP	0.0	0.0	0.0	0.0	0.0	31.8	81.9	91.4	0.0	**205.0**	**0.4**
Larkspur city	2.6	90.5	32.7	0.0	331.0	80.1	82.0	1,080.5	36.3	**1,735.7**	**3.5**
Lucas Valley-Marinwood CDP	10.4	16.8	0.0	0.0	361.5	176.0	14.2	589.7	0.0	**1,168.6**	**2.4**
Marin City CDP	0.0	33.6	0.0	0.0	128.4	4.0	14.9	36.6	0.0	**217.4**	**0.4**
Mill Valley city	1.1	75.5	0.0	0.0	89.9	563.6	89.6	1,772.7	64.9	**2,657.2**	**5.4**
Novato city	39.5	276.9	6.2	161.6	177.5	1,265.0	1,085.6	7,310.2	106.3	**10,428.9**	**21.1**
Ross town	0.0	0.0	0.0	0.0	0.9	0.0	26.5	785.9	2.4	**815.6**	**1.7**
San Anselmo town	0.4	39.9	0.0	0.0	120.0	0.2	114.6	1,340.4	37.8	**1,653.4**	**3.3**
San Geronimo CDP	0.0	0.0	0.0	0.0	0.0	0.0	8.3	156.7	0.5	**165.6**	**0.3**
San Rafael city	24.4	557.4	494.3	0.0	677.9	195.4	2,195.4	3,962.1	358.4	**8,465.5**	**17.1**
Santa Venetia CDP	89.3	2.8	1.6	0.0	51.8	2.9	41.3	432.2	0.0	**622.1**	**1.3**
Sausalito city	0.0	78.8	86.7	0.0	92.3	94.2	79.4	485.0	33.9	**950.4**	**1.9**
Sleepy Hollow CDP	53.1	0.0	0.0	0.0	354.7	87.8	3.7	528.4	0.0	**1,027.7**	**2.1**
Strawberry CDP	14.2	71.5	0.0	0.0	417.8	5.6	11.7	327.9	3.7	**852.5**	**1.7**
Tamalpais-Homestead Valley CDP	8.1	24.2	0.0	0.0	181.0	225.3	2.9	1,293.5	0.0	**1,735.0**	**3.5**
Tiburon town	0.6	0.0	3.6	0.0	196.4	374.5	132.4	1,355.5	32.6	**2,095.7**	**4.2**
Unincorporated	2,471.8	386.8	9.7	0.0	778.9	1,173.1	288.8	2,686.5	0.0	**7,795.6**	**15.8**
Woodacre CDP	53.3	0.7	0.0	0.0	0.0	0.0	58.1	526.8	8.3	**647.4**	**1.3**
Total	**2,916.2**	**1,770.1**	**656.6**	**161.6**	**4,164.3**	**4,710.0**	**4,838.7**	**29,343.0**	**820.2**	**49,380.7**	**100.0**
Percentage	**5.9**	**3.6**	**1.3**	**0.3**	**8.4**	**9.5**	**9.8**	**59.4**	**1.7**	**100.0**	

Table 17. Land cover (acre) by land use.

Land use	Tree	Shrub	Grass	BSDV	Building	Water	OtherImp
Agri	1,190	179	465	489	109	228	256
Com	177	98	226	171	211	120	767
Ind	46	24	46	58	151	12	320
Mix	23	4	27	28	25	0	55
MultiFam	1,492	297	466	455	515	141	799
OpenSpace	1,755	335	1,150	859	77	269	266
PQP	1,191	280	1,054	751	199	406	957
SingleFam	11,961	1,928	3,292	2,816	3,466	631	5,249
SmallCom	98	22	53	31	180	20	416
Total	**17,932**	**3,167**	**6,778**	**5,659**	**4,933**	**1,827**	**9,085**
Percent	**36.3**	**6.4**	**13.7**	**11.5**	**10.0**	**3.7**	**18.4**

Table 18. Land cover (%) by Jurisdiction.

Jurisdiction	Tree	Shrub	Grass	BSDV	Building	Water	OtherImp	Total
Alto CDP	28.8	5.6	8.9	5.1	13.8	0.0	37.8	100.0
Belvedere city	40.0	8.4	6.7	2.4	14.8	17.2	10.5	100.0
Black Point-Green Point CDP	45.8	4.3	22.7	13.2	2.8	2.2	8.9	100.0
Corte Madera town	31.8	8.1	16.0	4.7	13.4	2.1	23.9	100.0
Fairfax town	59.1	5.1	3.8	7.8	9.9	0.7	13.6	100.0
Kentfield CDP	55.8	4.9	5.5	3.9	10.5	1.2	18.2	100.0
Lagunitas-Forest Knolls CDP	19.8	7.6	10.9	49.6	1.8	0.6	9.7	100.0
Larkspur city	30.9	7.5	11.9	7.1	13.1	7.7	21.7	100.0
Lucas Valley-Marinwood CDP	33.7	4.8	10.8	14.2	12.5	0.6	23.4	100.0
Marin City CDP	24.8	7.6	12.0	10.7	12.2	0.7	32.1	100.0
Mill Valley city	47.1	7.1	8.4	8.2	9.1	2.8	17.4	100.0
Novato city	31.3	4.8	15.5	15.9	10.4	1.2	20.8	100.0
Ross town	67.5	4.2	4.5	3.7	6.8	0.4	12.8	100.0
San Anselmo town	49.4	7.1	4.2	12.6	12.8	0.3	13.6	100.0
San Geronimo CDP	62.9	4.6	5.2	10.3	4.1	1.3	11.5	100.0
San Rafael city	28.5	6.1	13.2	9.2	14.1	2.3	26.7	100.0
Santa Venetia CDP	26.5	5.8	14.8	9.2	13.5	6.3	23.8	100.0
Sausalito city	34.9	7.2	7.9	2.8	15.5	4.6	27.2	100.0
Sleepy Hollow CDP	45.2	6.9	7.4	21.9	6.8	0.5	11.3	100.0
Strawberry CDP	30.8	11.8	15.4	6.3	12.3	0.7	22.7	100.0
Tamalpais-Homestead Valley CDP	50.1	8.1	7.3	7.1	10.0	1.2	16.3	100.0
Tiburon town	30.7	12.6	25.5	6.5	10.6	0.7	13.4	100.0
Unincorporated	32.6	6.4	19.5	15.2	4.1	12.6	9.5	100.0
Woodacre CDP	57.8	7.4	5.0	16.1	3.4	0.3	10.0	100.0

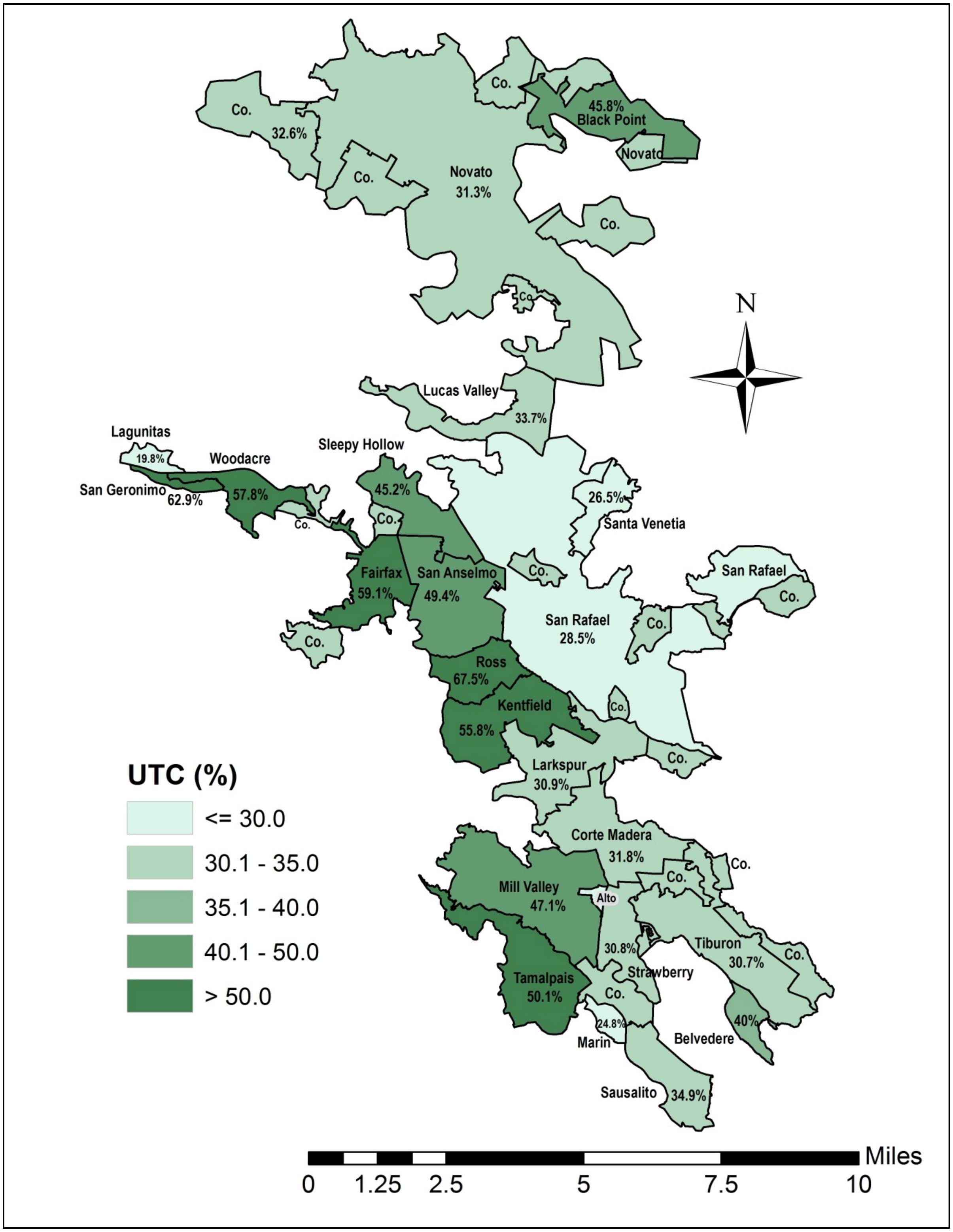


Figure 6. Percent urban tree canopy cover (UTC) by jurisdiction.

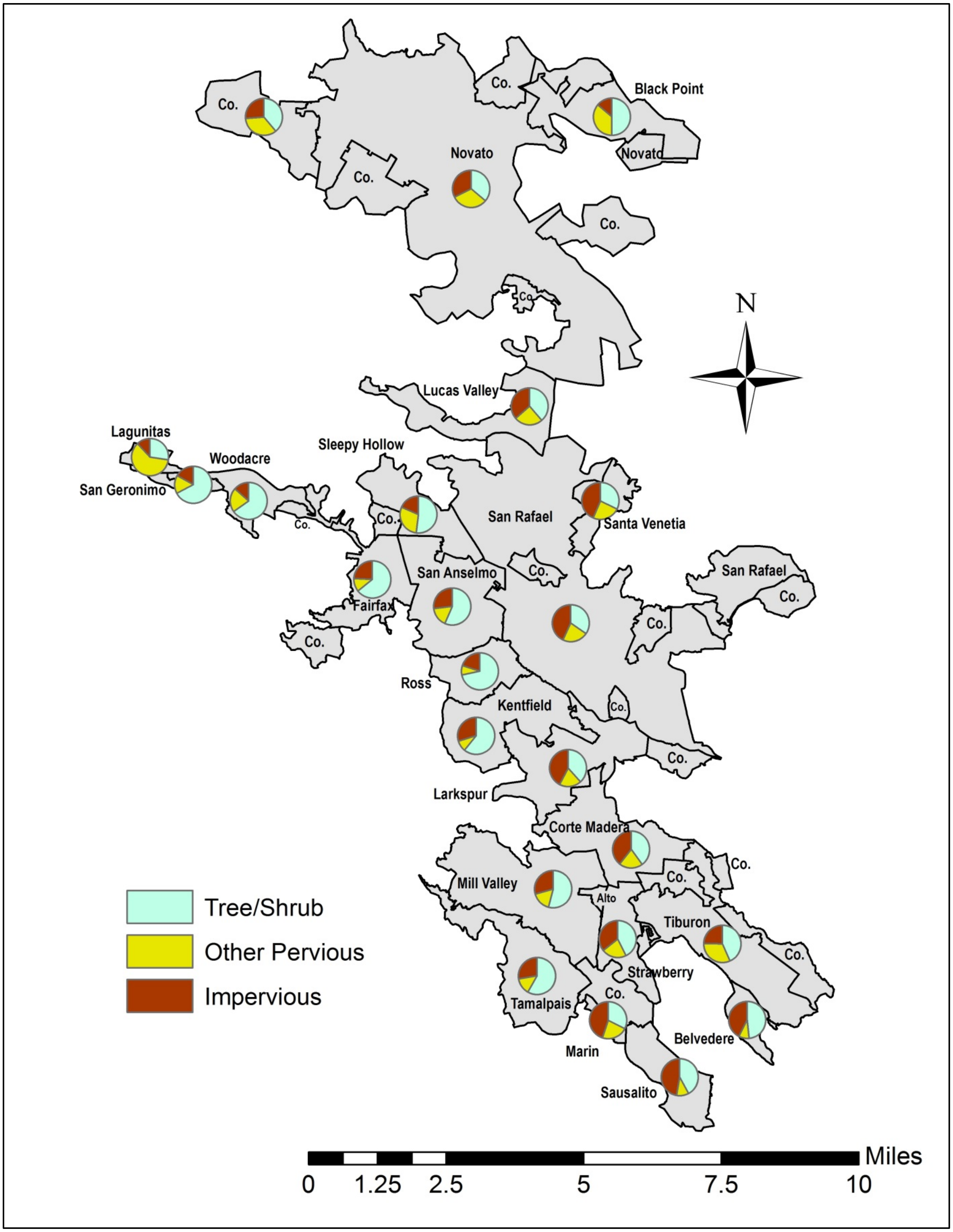


Figure 7. Proportions of tree/shrub, other pervious, and impervious land cover by jurisdiction.

Accuracy Assessment

The overall accuracy was 87%, slightly below the original specification of 90% (Table 19). Tree canopy had the highest consumer's accuracy for vegetation with 92%. This is not surprising given that this study focused on UTC. In contrast, the irrigated grass class had the lowest consumer's accuracy for vegetation. This class was difficult to detect in automated feature extraction because it lacked distinct spectral, textural, and physical properties in the source datasets that would facilitate discrimination from other classes. Inaccuracies were particularly evident in residential areas, where shadows and heterogeneous cover types were ubiquitous.

Table 19.Land cover classification error matrix using SFSU's reference data

		SFSU LCC Data								Producer's Accuracy
		Water	Tree	Dry grass	Wet grass	Shrub	Impervious	Building	Total	
Reference Data	**Water**	32	0	0	0	0	0	0	32	1.00
	Tree	0	356	0	4	2	0	1	363	0.98
	Dry	0	4	106	27	6	4	0	147	0.72
	Wet	0	5	8	85	1	9	0	108	0.79
	Shrub	0	9	3	6	60	0	1	79	0.76
	Impervious	0	11	11	4	1	156	0	183	0.85
	Building	0	0	1	1	0	7	79	88	0.90
	Total	32	385	129	127	70	176	81	1,000	
Consumer's Accuracy		1.00	0.92	0.82	0.67	0.86	0.89	0.98		0.87

Existing Trees

Marin County has 17,932 acres of urban tree canopy cover equating to 36.3%. UTC ranged from 19.8% in Lagunitas-Forest Knolls CDP to 67.5% in Ross town (Figure 6). Over two thirds (66.7%) of the region's UTC was within the single-family residential land use class, where trees can reduce home energy use. Unit energy consumption is higher for single-family buildings than for other building types, so residential trees provide potentially greater energy savings. These depend, however, on the location of the tree to the building (Simpson 2002). Large trees on the west side of a building usually provide the highest cooling energy savings for California climates (McPherson and Simpson 2003, Simpson and McPherson 2001). Land use classes with less than 1% UTC were commercial, small commercial, industrial, and areas of mixed land use (Table 16).

There are approximately 1.9 million existing trees (Table 20 and Table 21) in urbanized Marin County. Jurisdictions with the highest number of trees were Novato (350,172), San Rafael (258,146) and Mill Valley (133,999) (Table 12). Unincorporated areas contain 272,615 trees. The average number of trees per acre in Marin is 38.9, which is greater than values reported for San Jose (31.8), Sacramento (21.8) and Los Angeles (19.9). Within Marin County, tree density values ranged from a high of 72 to a low of 21 trees per acre. Cities with the highest tree density were Fairfax town, Ross city, San Geronimo CDP, and Woodacre CDP.

The average number of trees per capita in Marin County was 8.8, with values ranging from 3.5 in Alto CDP to 66 in Black point-Green Point CDP and 434 in Lagunitas-Forest Knolls CDP; the latter has a very low population. The average value of 8.8 trees per capita is high compared to values reported for San Jose (3.2), Sacramento (2.8) and Los Angeles (1.6). An abundance of native oaks that thrive in undisturbed areas may explain the relatively large numbers of trees per capita, as well as high tree density and UTC.

Table 20. Urban tree canopy (%), tree count, tree density as well as population density by jurisdiction.

Jurisdiction	UTC (%)	# Trees	Trees/capita	Trees/ac	Population/ac
Alto CDP	28.8	2,484	3.5	30.9	8.8
Belvedere city	40.0	16,888	8.2	42.8	5.2
Black Point-Green Point CDP	45.8	67,650	66.1	49.1	0.7
Corte Madera town	31.8	55,437	6.2	34.1	5.5
Fairfax town	59.1	68,125	10.7	63.3	5.9
Kentfield CDP	55.8	94,961	14.8	59.8	4.0
Lagunitas-Forest Knolls CDP	19.8	4,340	434.0	21.2	0.0
Larkspur city	30.9	57,393	5.2	33.1	6.4
Lucas Valley-Marinwood CDP	33.7	42,139	9.6	36.1	3.7
Marin City CDP	24.8	5,787	2.6	26.6	10.2
Mill Valley city	47.1	133,999	10.6	50.4	4.7
Novato city	31.3	350,172	7.5	33.6	4.5
Ross town	67.5	58,993	27.2	72.3	2.7
San Anselmo town	49.4	87,580	7.4	53.0	7.2
San Geronimo CDP	62.9	11,157	51.4	67.4	1.3
San Rafael city	28.5	258,146	4.8	30.5	6.4
Santa Venetia CDP	26.5	17,693	4.8	28.4	5.9
Sausalito city	34.9	35,495	5.1	37.3	7.3
Sleepy Hollow CDP	45.2	49,718	42.9	48.4	1.1
Strawberry CDP	30.8	28,165	5.2	33.0	6.3
Tamalpais-Homestead Valley CDP	50.1	93,050	11.6	53.6	4.6
Tiburon town	30.7	68,960	7.7	32.9	4.3
Unincorporated	32.6	272,615	22.2	35.0	1.6
Woodacre CDP	57.8	40,071	43.5	61.9	1.4
Total	**36.3**	**1,921,018**	**8.8**	**38.9**	**4.4**

Table 21. Number of trees by land use and jurisdiction.

Jurisdiction	Agri	Com	Ind	Mix	MultiFam	OpenSpace	PQP	SingleFam	SmallCom	Total
Alto CDP	39	71	-	-	147	117	-	2,110	-	2,484
Belvedere city	-	-	-	-	489	604	246	15,455	94	16,888
Black Point-Green Point CDP	9,097	-	-	-	39	2,909	317	54,999	289	67,650
Corte Madera town	-	987	294	-	4,028	802	9,012	39,051	1,263	55,437
Fairfax town	-	193	-	-	39	10,290	1,122	56,378	103	68,125
Kentfield CDP	-	144	-	-	2,311	6,205	1,896	84,402	3	94,961
Lagunitas-Forest Knolls CDP	-	-	-	-	-	782	1,680	1,878	-	4,340
Larkspur city	4	801	245	-	9,558	5,407	779	39,891	708	57,393
Lucas Valley-Marinwood CDP	285	400	-	-	15,646	8,509	440	16,859	-	42,139
Marin City CDP	-	271	-	-	3,986	82	184	1,264	-	5,787
Mill Valley city	13	1,037	-	-	2,386	28,576	843	99,684	1,460	133,999
Novato city	1,384	2,722	20	2,491	5,383	51,695	14,295	271,077	1,105	350,172
Ross town	-	-	-	-	36	-	1,155	57,742	60	58,993
San Anselmo town	31	782	-	-	4,214	2	4,721	77,068	762	87,580
San Geronimo CDP	-	-	-	-	-	-	207	10,939	11	11,157
San Rafael city	1,455	4,300	3,163	-	17,918	5,365	79,152	143,260	3,533	258,146
Santa Venetia CDP	5,049	28	1	-	2,004	37	205	10,369	-	17,693
Sausalito city	-	403	1,155	-	3,378	4,384	1,494	24,349	332	35,495
Sleepy Hollow CDP	2,719	-	-	-	17,163	3,329	303	26,204	-	49,718
Strawberry CDP	673	695	-	-	13,708	328	400	12,293	68	28,165
Tamalpais-Homestead Valley CDP	447	157	-	-	9,933	13,770	70	68,670	3	93,050
Tiburon town	47	-	14	-	6,012	8,300	2,723	51,414	450	68,960
Unincorporated	101,742	5,896	36	-	41,454	36,523	5,100	81,864	-	272,615
Woodacre CDP	4,460	24	-	-	-	-	1,215	34,138	234	40,071
Total	**127,445**	**18,911**	**4,928**	**2,491**	**159,832**	**188,016**	**127,559**	**1,281,358**	**10,478**	**1,921,018**
Percentage	**6.6**	**1.0**	**0.3**	**0.1**	**8.3**	**9.8**	**6.6**	**66.7**	**0.5**	**100.0**

Stocking level is defined as the percentage of total greenspace that is filled with UTC, where greenspace is all pervious surface cover (i.e., UTC, irrigated grass, bare soil/dry vegetation). The average stocking level for the study area is 82%. Jurisdictions with over 90% are Belvedere city, Fairfax town, Kentfield CDP, Ross town, San Anselmo town, San Geronimo CDP, Tamalpais-Homestead Valley CDP, and Woodacre CDP. Lagunitas-Forest Knolls CDP had the lowest stocking level (63%), indicating greater potential to increase UTC than jurisdictions with higher stocking (Table 22). Stocking levels in Marin County are relatively high (Table 23) compared to levels reported for Pasadena (42%), Metro Sacramento (38%), San Jose (37%) and Los Angeles (36%).

Table 22.Current stocking level (%).

Jurisdiction	Agri	Com	Ind	Mix	MultiFam	OpenSpace	PQP	SingleFam	SmallCom	Total
Alto CDP	75	67	-	-	97	79	-	86	-	85
Belvedere city	-	-	-	-	83	94	80	92	86	92
Black Point-Green Point CDP	86	-	-	-	67	44	49	81	61	79
Corte Madera town	-	81	84	-	82	78	59	86	80	79
Fairfax town	-	94	-	-	100	95	90	96	97	95
Kentfield CDP	-	92	-	-	97	88	81	96	100	95
Lagunitas-Forest Knolls CDP	-	-	-	-	-	68	56	68	-	63
Larkspur city	21	50	73	-	81	95	50	83	92	82
Lucas Valley-Marinwood CDP	68	81	-	-	83	81	73	84	-	83
Marin City CDP	-	49	-	-	83	55	45	82	-	78
Mill Valley city	42	66	-	-	82	83	43	94	93	90
Novato city	69	64	14	58	77	76	45	80	69	77
Ross town	-	-	-	-	95	-	88	96	98	96
San Anselmo town	100	91	-	-	90	40	84	94	91	93
San Geronimo CDP	-	-	-	-	-	-	59	95	85	94
San Rafael city	85	54	54	-	85	52	74	85	68	79
Santa Venetia CDP	90	97	3	-	88	44	23	73	-	76
Sausalito city	-	63	90	-	92	83	70	93	79	89
Sleepy Hollow CDP	87	-	-	-	86	79	94	90	-	88
Strawberry CDP	87	80	-	-	74	85	85	85	79	79
Tamalpais-Homestead Valley CDP	94	77	-	-	90	88	91	93	100	92
Tiburon town	100	-	67	-	75	47	54	77	77	70
Unincorporated	79	49	42	-	88	62	65	73	-	74
Woodacre CDP	97	73	-	-	0	0	58	94	88	93
Total	**81**	**58**	**61**	**58**	**84**	**73**	**66**	**86**	**77**	**82**

Table 23. Tree and human population statistics for selected cities.

City	Population	Study area (ac)	Population density (people/ac)	Tree cover (%)	Number of trees	Trees per capita	Tree density (trees/ac)
Casper, WY	55,316	13,419	4.1	8.9	123,000	2.2	9.2
Chicago, IL	2,700,000	147,609	18.3	17.2	3,585,000	1.3	24.3
Denver Metro, CO	2,700,000	460,719	5.9	15.7	10,713,292	4.0	23.3
Jersey City, NJ	248,000	9,585	25.9	11.5	136,000	0.5	14.2
Los Angeles, CA	3,800,000	300,969	12.6	11.1	6,000,000	1.6	19.9
Marin, CA	**252,789**	**49,380**	**5.1**	**36.6**	**1,921,102**	**7.6**	**38.9**
Minneapolis, MN	382,000	37,062	10.3	26.4	979,000	2.6	26.4
New York, NY	19,465,000	196,812	98.9	20.9	5,212,000	0.3	26.5
Philadelphia, PA	1,526,000	84,348	18.1	15.7	2,113,000	1.4	25.1
Sacramento Metro, CA	2,500,000	322,695	7.7	17.0	6,889,000	2.8	21.3
San Jose, CA	952,612	96,489	9.9	15.4	3,068,325	3.2	31.8

*(McPherson et al. in review, McPherson et al. 2013, Nowak and Crane 2002, Nowak 2006, Nowak et al. 2007a, b, Nowak et al. 2010)

Potential Tree Planting Sites

Pervious surfaces

Marin County has 425,488 potential tree planting sites. The majority, 238,000 (56%), are in residential land uses and 70,740 (16%) are in open space land. Public/quasi-public land contains 64,344 sites (15%), agricultural land has 30,182 (8%), commercial has 13,924 (4%), and industrial and mixed have less than 2% each.

The cities with the most PTPS are Novato (106,000) and San Rafael (68,000); Table 24. Unincorporated areas contain 94,242 PTPS in Marin County (Appendix II shows examples of PTPS by census block. Detailed tables like this can be found for all of the datasets in digital form submitted with this report).

Over 81% of the PTPS, or 345,013, are located in irrigated grass (Table 25). Planting trees in irrigated grass allows for desirable use of resources because additional irrigation would likely not be needed.

Building energy savings from tree shade is location specific. Prioritizing tree plantings to focus on large-stature trees to the west side of buildings in irrigated grass would maximize energy benefits for cooling at minimal cost for irrigation.

Appendix II shows examples of PTPS by census block group. Detailed tables like this can be found for all of the datasets in digital form submitted with this report.

Table 24. Number of potential tree planting sites (PTPS) for the irrigated and dry grass land cover class.

Jurisdiction	Irrigated grass	BSDV	Total
Alto CDP	364	58	422
Belvedere city	1,336	137	1,473
Black Point-Green Point CDP	15,932	2,593	18,525
Corte Madera town	13,283	1,095	14,378
Fairfax town	2,087	1,189	3,276
Kentfield CDP	4,423	873	5,296
Lagunitas-Forest Knolls CDP	1,142	1,448	2,590
Larkspur city	10,538	1,762	12,300
Lucas Valley-Marinwood CDP	6,449	2,356	8,805
Marin City CDP	1,327	330	1,657
Mill Valley city	11,398	3,086	14,484
Novato city	82,416	23,644	106,060
Ross town	1,877	435	2,312
San Anselmo town	3,531	2,955	6,486
San Geronimo CDP	442	243	685
San Rafael city	56,720	11,131	67,851
Santa Venetia CDP	4,679	816	5,495
Sausalito city	3,816	379	4,195
Sleepy Hollow CDP	3,877	3,206	7,083
Strawberry CDP	6,684	764	7,448
Tamalpais-Homestead Valley CDP	6,423	1,752	8,175
Tiburon town	27,176	1,941	29,117
Unincorporated	77,443	16,799	94,242
Woodacre CDP	1,650	1,483	3,133
Total	**345,013**	**80,475**	**425,488**

Table 25. Potential tree planting sites (PTPS) by land cover class and jurisdiction.

Jurisdiction	Agri	Com	Ind	Mix	MultiFam	OpenSpace	PQP	SingleFam	SmallCom	Total
Alto CDP	13	35	0	0	5	32	0	337	0	422
Belvedere city	0	0	0	0	99	38	63	1,258	15	1,473
Black Point-Green Point CDP	1,498	0	0	0	19	3,675	336	12,815	182	18,525
Corte Madera town	0	231	54	0	868	220	6,298	6,394	313	14,378
Fairfax town	0	13	0	0	0	591	118	2,551	3	3,276
Kentfield CDP	0	13	0	0	70	840	433	3,940	0	5,296
Lagunitas-Forest Knolls CDP	0	0	0	0	0	360	1,339	891	0	2,590
Larkspur city	15	810	92	0	2,227	299	778	8,017	62	12,300
Lucas Valley-Marinwood CDP	132	93	0	0	3,155	2,013	160	3,252	0	8,805
Marin City CDP	0	283	0	0	809	66	225	274	0	1,657
Mill Valley city	18	540	0	0	531	5,845	1,119	6,326	105	14,484
Novato city	628	1,542	121	1,768	1,607	16,290	17,812	65,802	490	106,060
Ross town	0	0	0	0	2	0	151	2,158	1	2,312
San Anselmo town	0	80	0	0	475	3	929	4,924	75	6,486
San Geronimo CDP	0	0	0	0	0	0	142	541	2	685
San Rafael city	255	3,605	2,662	0	3,266	4,912	27,132	24,392	1,627	67,851
Santa Venetia CDP	541	1	29	0	269	47	695	3,913	0	5,495
Sausalito city	0	235	133	0	275	871	644	1,949	88	4,195
Sleepy Hollow CDP	403	0	0	0	2,764	883	18	3,015	0	7,083
Strawberry CDP	102	177	0	0	4,845	60	68	2,178	18	7,448
Tamalpais-Homestead Valley CDP	31	48	0	0	1,059	1,898	7	5,132	0	8,175
Tiburon town	0	0	7	0	1,983	9,415	2,289	15,290	133	29,117
Unincorporated	26,835	6,209	50	0	5,854	22,382	2,726	30,186	0	94,242
Woodacre CDP	134	9	0	0	0	0	862	2,095	33	3,133
Total	**30,605**	**13,924**	**3,148**	**1,768**	**30,182**	**70,740**	**64,344**	**207,630**	**3,147**	**425,488**

Additional tree planting

The target for tree planting was to fill 50% of the PTPS using 30-ft crown diameter trees in irrigated grass and 50-ft crown diameter trees in bare soil/dry vegetation. This would result in the planting of 212,811 trees (Table 26), adding 4,615 acres of UTC once trees in all the sites mature (Table 27). The majority would be in Novato and San Rafael city while the fewest would be located in Alto and San Geronimo CDP (Figure 8). Over half would be within the residential zoning class, which is desirable as it increases ecosystem services, mainly energy reductions due to shade. These calculations assume that current UTC remains stable and program tree sites remain fully stocked with 30-ft and 50-ft crown diameter trees. Because some program trees will die and need to be replaced, more than 212,811 trees will need to be planted to keep additional sites fully stocked. It is conservatively assumed that it will take 30 years to achieve the projected level of canopy cover after planting.

Table 26. Additional trees by land use and jurisdiction.

Jurisdiction	Agri	Com	Ind	Mix	MultiFam	OpenSpace	PQP	SingleFam	SmallCom	Total
Alto CDP	7	18	0	0	3	16	0	169	0	213
Belvedere city	0	0	0	0	50	20	32	629	8	739
Black Point-Green Point CDP	749	0	0	0	10	1,838	169	6,408	91	9,265
Corte Madera town	0	116	27	0	434	110	3,149	3,197	157	7,190
Fairfax town	0	7	0	0	0	296	59	1,276	2	1,640
Kentfield CDP	0	7	0	0	35	421	217	1,971	0	2,651
Lagunitas-Forest Knolls CDP	0	0	0	0	0	181	670	446	0	1,297
Larkspur city	8	405	46	0	1,114	150	390	4,009	31	6,153
Lucas Valley-Marinwood CDP	67	47	0	0	1,578	1,007	81	1,626	0	4,406
Marin City CDP	0	142	0	0	405	34	113	138	0	832
Mill Valley city	10	271	0	0	266	2,923	560	3,163	53	7,246
Novato city	314	772	61	884	804	8,145	8,906	32,902	245	53,033
Ross town	0	0	0	0	2	0	76	1,080	1	1,159
San Anselmo town	0	40	0	0	238	2	465	2,462	38	3,245
San Geronimo CDP	0	0	0	0	0	0	72	271	2	345
San Rafael city	128	1,803	1,331	0	1,633	2,457	13,566	12,196	814	33,928
Santa Venetia CDP	271	1	15	0	135	24	348	1,957	0	2,751
Sausalito city	0	118	67	0	138	436	322	975	45	2,101
Sleepy Hollow CDP	202	0	0	0	1,382	442	9	1,508	0	3,543
Strawberry CDP	52	89	0	0	2,423	31	35	1,090	9	3,729
Tamalpais-Homestead Valley CDP	16	24	0	0	530	949	4	2,566	0	4,089
Tiburon town	0	0	4	0	992	4,708	1,145	7,646	67	14,562
Unincorporated	13,418	3,105	26	0	2,928	11,192	1,363	15,093	0	47,125
Woodacre CDP	68	5	0	0	0	0	431	1,048	17	1,569
Total	**15,310**	**6,970**	**1,577**	**884**	**15,100**	**35,382**	**32,182**	**103,826**	**1,580**	**212,811**

Table 27. Additional urban tree cover (acres) from 212,811 trees.

Jurisdiction	Agri	Com	Ind	Mix	MultiFam	OpenSpace	PQP	SingleFam	SmallCom	Total
Alto CDP	0.1	0.6	0.0	0.0	0.0	0.5	0.0	3.1	0.0	4.3
Belvedere city	0.0	0.0	0.0	0.0	0.9	0.5	0.7	11.7	0.2	14.0
Black Point-Green Point CDP	12.6	0.0	0.0	0.0	0.2	30.3	4.2	138.6	1.8	187.8
Corte Madera town	0.0	2.3	0.6	0.0	8.7	2.2	56.3	59.5	3.0	132.5
Fairfax town	0.0	0.2	0.0	0.0	0.0	9.5	1.6	32.4	0.1	43.8
Kentfield CDP	0.0	0.2	0.0	0.0	0.8	8.4	4.5	41.8	0.0	55.7
Lagunitas-Forest Knolls CDP	0.0	0.0	0.0	0.0	0.0	7.0	19.5	15.4	0.0	42.0
Larkspur city	0.1	8.2	1.3	0.0	21.9	3.9	8.8	80.3	0.8	125.3
Lucas Valley-Marinwood CDP	1.7	1.0	0.0	0.0	38.6	28.9	1.5	33.8	0.0	105.5
Marin City CDP	0.0	2.9	0.0	0.0	9.2	0.8	2.6	2.9	0.0	18.3
Mill Valley city	0.2	5.0	0.0	0.0	5.6	60.6	11.3	78.2	1.3	162.1
Novato city	8.4	17.1	1.3	20.1	17.4	187.3	171.8	772.6	5.7	1,201.7
Ross town	0.0	0.0	0.0	0.0	0.1	0.0	1.5	23.5	0.0	25.1
San Anselmo town	0.0	1.1	0.0	0.0	7.4	0.1	16.7	68.9	1.3	95.3
San Geronimo CDP	0.0	0.0	0.0	0.0	0.0	0.0	2.0	7.1	0.1	9.1
San Rafael city	2.3	34.5	31.8	0.0	35.8	45.9	296.5	249.6	14.9	711.1
Santa Venetia CDP	5.9	0.0	0.5	0.0	3.1	0.6	6.1	40.3	0.0	56.4
Sausalito city	0.0	2.3	1.4	0.0	2.7	7.9	6.6	17.8	1.0	39.6
Sleepy Hollow CDP	6.8	0.0	0.0	0.0	44.4	16.4	0.3	35.9	0.0	103.7
Strawberry CDP	1.0	2.1	0.0	0.0	47.0	0.6	0.7	20.1	0.2	71.6
Tamalpais-Homestead Valley CDP	0.4	0.8	0.0	0.0	12.6	20.1	0.1	57.6	0.0	91.7
Tiburon town	0.0	0.0	0.1	0.0	17.6	90.9	21.3	133.2	1.3	264.3
Unincorporated	307.5	70.1	0.5	0.0	64.8	228.2	28.8	307.3	0.0	1,007.1
Woodacre CDP	2.0	0.1	0.0	0.0	0.0	0.0	13.1	31.1	0.5	46.9
Total	**348.9**	**148.4**	**37.4**	**20.1**	**338.6**	**750.5**	**676.4**	**2,262.6**	**32.1**	**4,615.0**

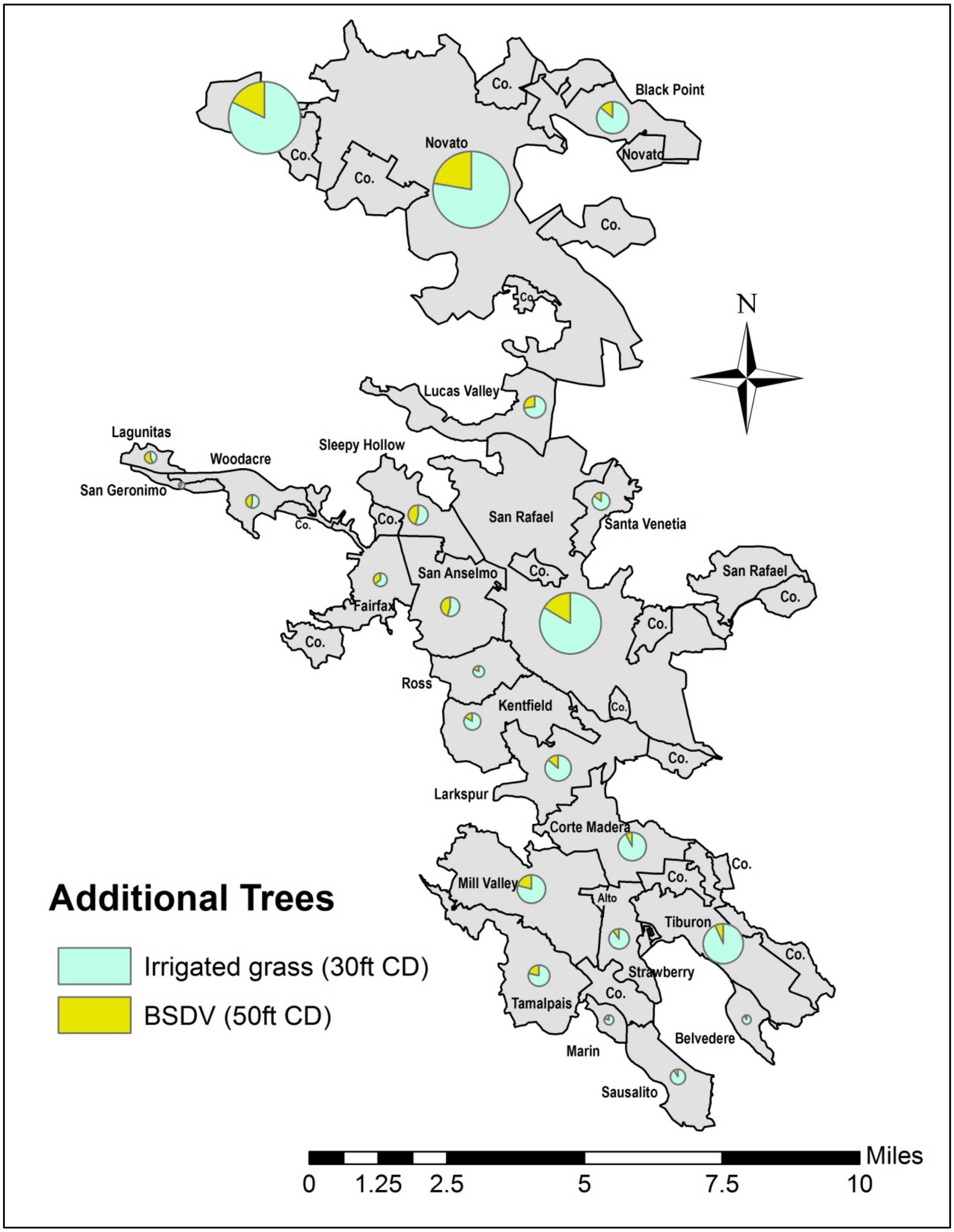


Figure 8. Proportion of additional trees by pervious land cover class, irrigated grass or bare soil/dry vegetation.

The planting of 212,811 trees would increase the UTC by 9.4% from 36.6 to 45.7% (Table 28). UTC will increase to greater than 50% in 10 jurisdictions and exceed 60% in three (Fairfax town, Ross town, Woodacre CDP). Stocking will increase to 91% (Table 29), with all jurisdictions exceeding 80%. Proportion of current and additional canopy can be seen in Figure 9 while percent full stock of current and additional trees is presented in Figure 10.

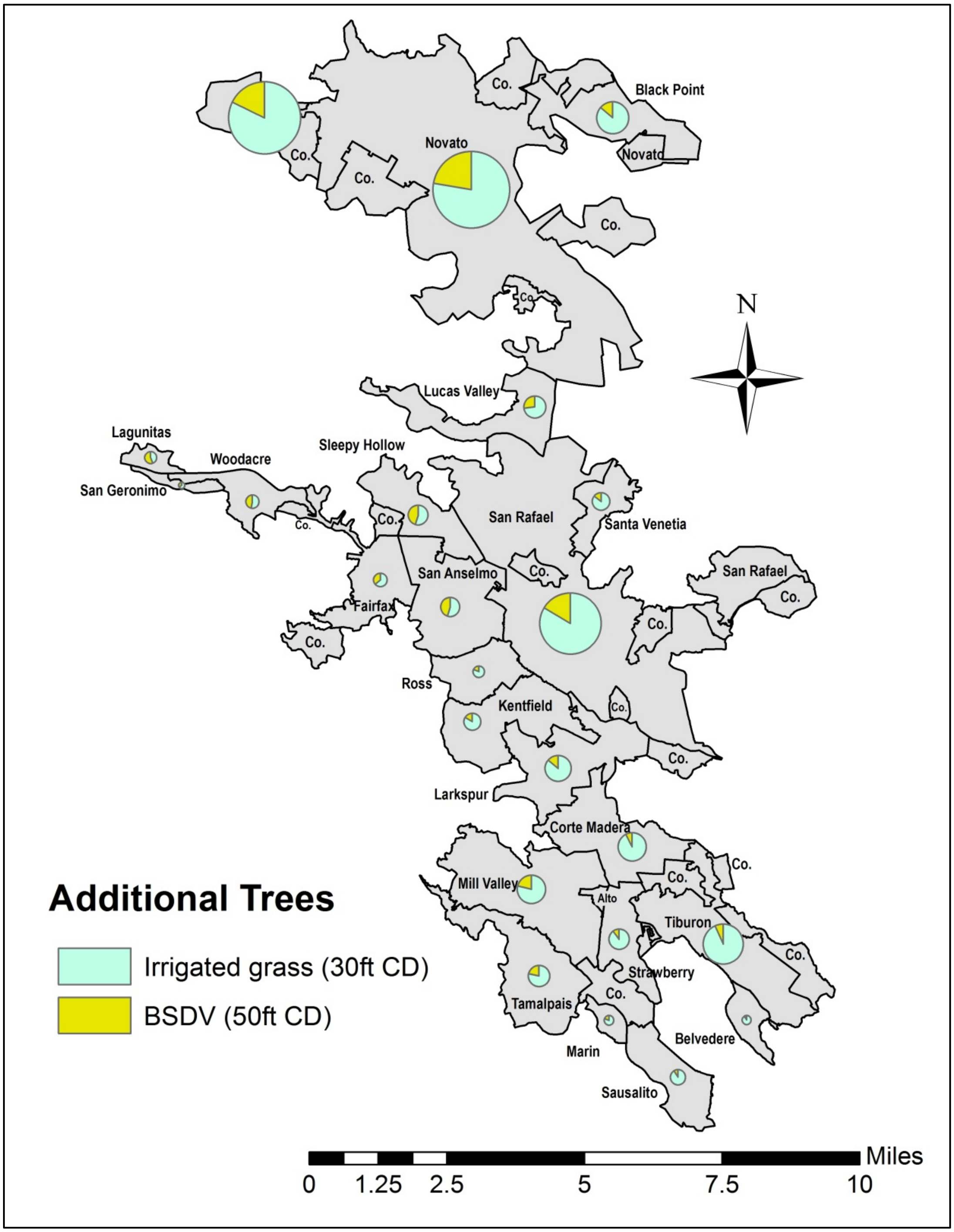


Figure 8. Proportion of additional trees by pervious land cover class, irrigated grass or bare soil/dry vegetation.

Table 28. Existing and additional UTC based on filling 50% of PTPS.

Jurisdiction	# Trees	Existing UTC (%)	Additional UTC (%)	Existing & Additional UTC (%)
Alto CDP	2,484	28.8	5.4	34.2
Belvedere city	16,888	40.0	3.6	43.5
Black Point-Green Point CDP	67,650	45.8	13.6	59.5
Corte Madera town	55,437	31.8	8.1	40.0
Fairfax town	68,125	59.1	4.1	63.2
Kentfield CDP	94,961	55.8	3.5	59.4
Lagunitas-Forest Knolls CDP	4,340	19.8	20.5	40.2
Larkspur city	57,393	30.9	7.2	38.1
Lucas Valley-Marinwood CDP	42,139	33.7	9.0	42.7
Marin City CDP	5,787	24.8	8.4	33.3
Mill Valley city	133,999	47.1	6.1	53.2
Novato city	350,172	31.3	11.5	42.9
Ross town	58,993	67.5	3.1	70.6
San Anselmo town	87,580	49.4	5.8	55.2
San Geronimo CDP	11,157	62.9	5.5	68.4
San Rafael city	258,146	28.5	8.4	36.9
Santa Venetia CDP	17,693	26.5	9.1	35.6
Sausalito city	35,495	34.9	4.2	39.0
Sleepy Hollow CDP	49,718	45.2	10.1	55.3
Strawberry CDP	28,165	30.8	8.4	39.2
Tamalpais-Homestead Valley CDP	93,050	50.1	5.3	55.3
Tiburon town	68,960	30.7	12.6	43.3
Unincorporated	272,615	32.6	12.9	45.6
Woodacre CDP	40,071	57.8	7.2	65.0
Total	**1,921,018**	**36.3**	**9.3**	**45.7**

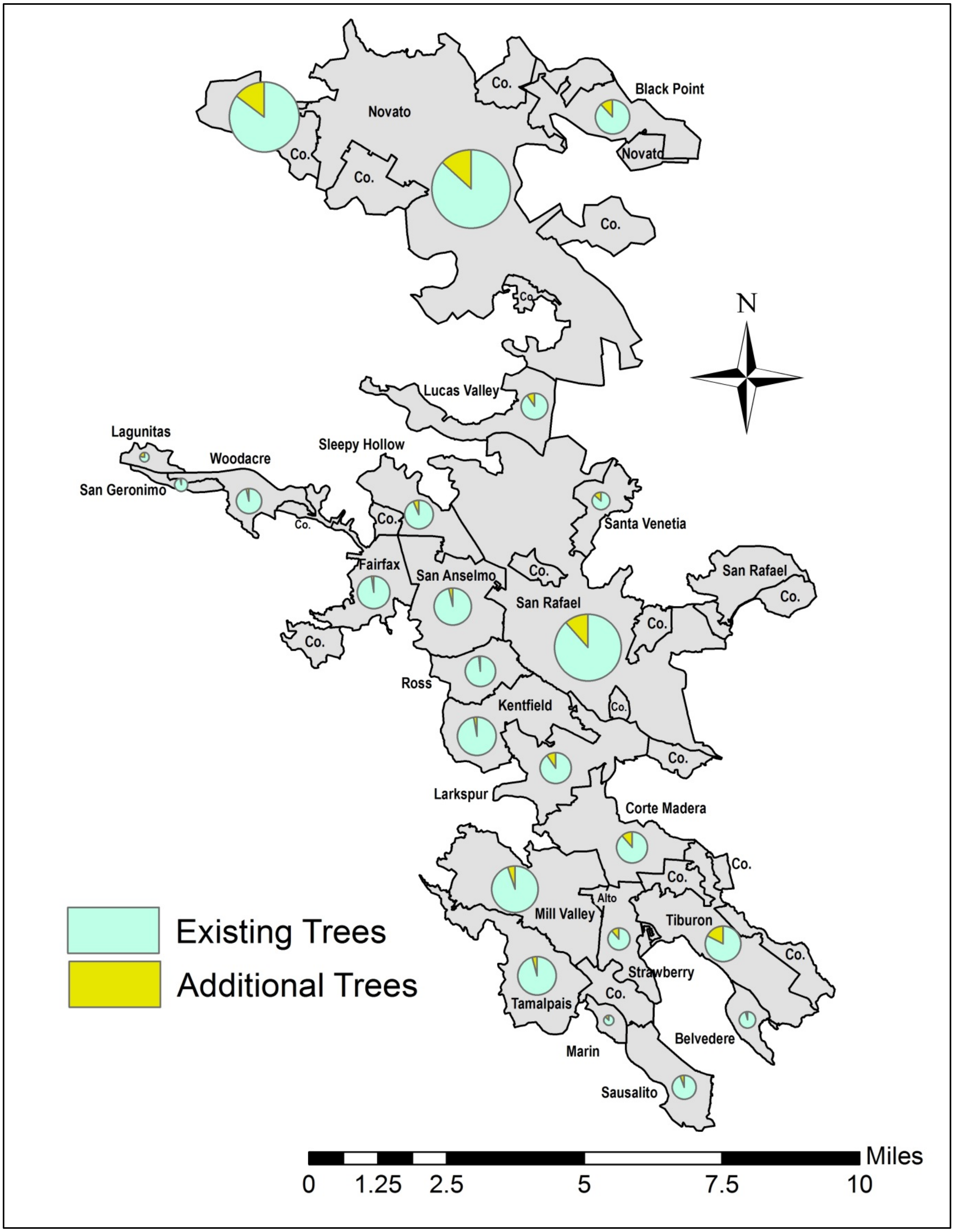


Figure 9. Proportion of current and additional canopy.

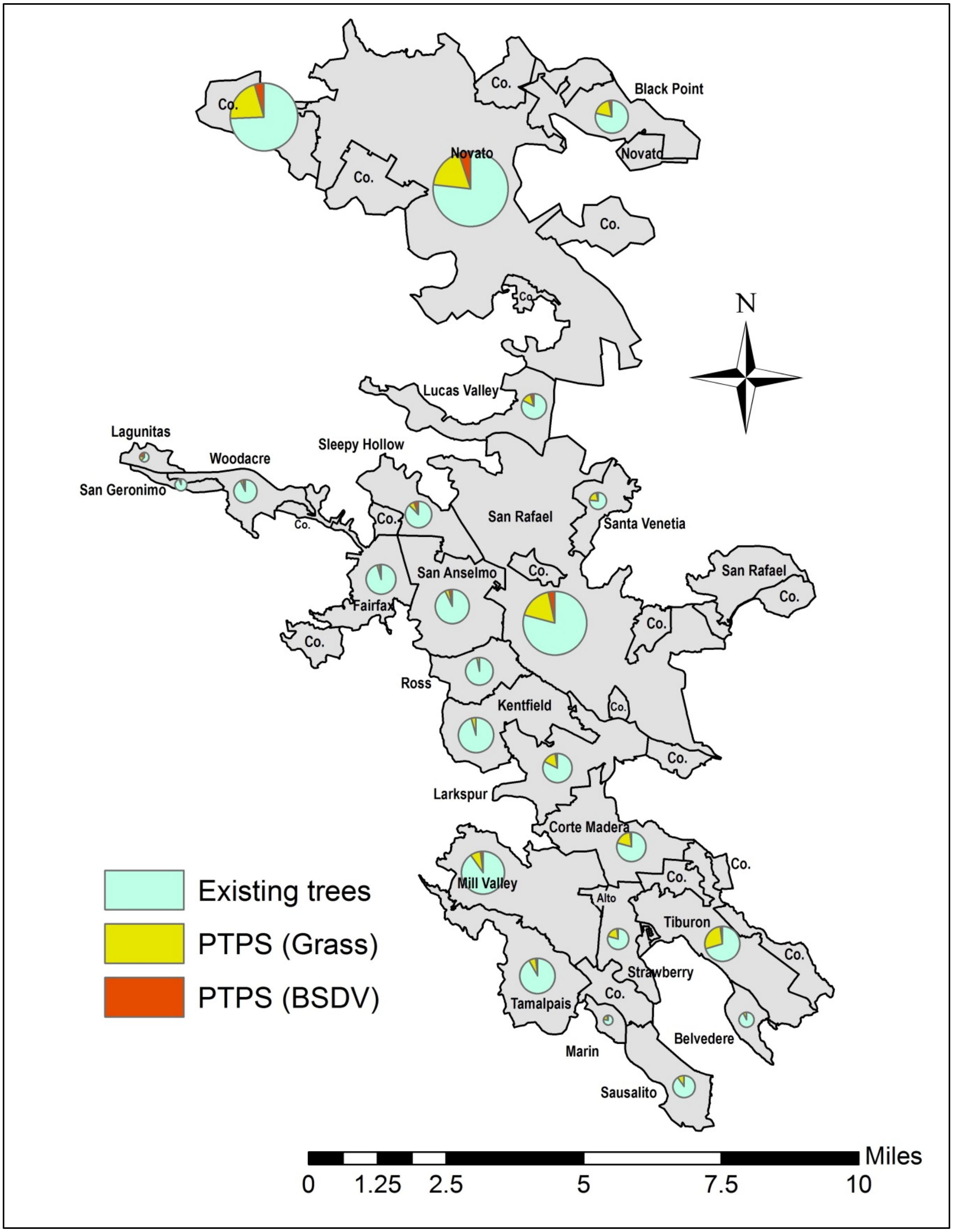


Figure 10. Proportion of percent full stock by current and additional canopy.

Table 29. Percent full stocking for existing plus additional UTC.

Jurisdiction	Agri	Com	Ind	Mix	MultiFam	OpenSpace	PQP	SingleFam	SmallCom	Total
Alto CDP	88	84	0	0	99	89	0	93	0	93
Belvedere city	0	0	0	0	92	97	90	96	94	96
Black Point-Green Point CDP	93	0	0	0	84	72	74	91	81	89
Corte Madera town	0	91	92	0	91	89	79	93	90	90
Fairfax town	0	97	0	0	100	97	95	98	99	98
Kentfield CDP	0	96	0	0	99	94	91	98	100	97
Lagunitas-Forest Knolls CDP	0	0	0	0	0	84	78	84	0	81
Larkspur city	63	75	86	0	91	97	75	92	96	91
Lucas Valley-Marinwood CDP	84	91	0	0	92	90	87	92	0	91
Marin City CDP	0	75	0	0	92	78	73	91	0	89
Mill Valley city	74	83	0	0	91	92	72	97	97	95
Novato city	84	82	57	79	89	88	72	90	85	88
Ross town	0	0	0	0	100	0	94	98	100	98
San Anselmo town	100	95	0	0	95	80	92	97	96	97
San Geronimo CDP	0	0	0	0	0	0	80	98	100	97
San Rafael city	93	77	77	0	92	76	87	93	84	90
Santa Venetia CDP	95	100	53	0	94	73	61	86	0	88
Sausalito city	0	82	95	0	96	92	85	96	90	95
Sleepy Hollow CDP	94	0	0	0	93	90	97	95	0	94
Strawberry CDP	94	90	0	0	87	93	93	92	90	90
Tamalpais-Homestead Valley CDP	97	88	0	0	95	94	96	97	100	96
Tiburon town	100	0	86	0	88	73	77	89	89	85
Unincorporated	90	74	72	0	94	81	83	87	0	87
Woodacre CDP	99	88	0	0	0	0	79	97	94	96
Total	**90**	**79**	**81**	**79**	**92**	**86**	**83**	**93**	**88**	**91**

Parking lot demonstration

The example parking lot area is 91,490-ft^2 and thus 45,745-ft^2 of UTC is needed to reach the 50% target. There is no existing tree cover within the parking lot boundary. Sites for 24 large trees and 66 medium trees were identified (Table 30, Figure 11 & Figure 12). Once planted and mature, UTC from these trees would increase to 47,124-ft^2 and 46,653-ft^2 or 51.5 and 51%, respectively. After merging the polygons and deleting UTC outside the parking lot boundary, medium trees resulted in 32,752-ft^2 and large trees 42,627-ft^2 of canopy cover. A total net canopy cover of 35.8% and 46.6%, respectively, was reached. One of the main challenges to reaching 50% canopy cover is crown overlap, especially for the medium-sized trees. Since the number of parking stalls is unchanged, trees could only be placed between double-stall rows and at the perimeter of the parking lot. Placing more trees closer together results in higher tree cover, but at the expense of greater crown overlap. Because the large-tree design had very little overlap it resulted in the highest net canopy cover of 47%.

Table 30. Number of trees and canopy cover for two parking lot designs. Medium trees have a 30-ft (9.1 m) crown diameter and large trees 50-ft (15.2 m).

Design	Existing canopy (%)	Canopy needed to reach 50% UTC (%)	Number of trees needed	Number of trees accomodated	% canopy (existing + additional)*
Med. tree	0	50	65	66	35.8
Large tree			23	24	46.6

* overlapping canopy as well as canopy outside the parking lot boundary was excluded

Figure 11. Parking lot design for medium trees (30-ft [9.1m] crown diameter).

Figure 12. Parking lot design for large trees (50-ft [15.2m] crown diameter).

Ecosystem Service Assessment

Appendix II shows examples of ecosystem services for the existing and potential canopy by census block group. Detailed tables like this can be found for all of the datasets in digital form submitted with this report.

Ecosystem Services provided by existing UTC

The annual value of ecosystem services and property value increases (Table 31) provided by existing UTC is $273 million (Table 32). Urban tree canopy was estimated to increase property values and provide other intangible benefits valued at $198 million annually or 73% of the total. Energy savings and rainfall interception accounted for $64 million (23%) and $8.5 million (3%). Atmospheric carbon dioxide reduction was valued at $1.2 million. Marin's urban forest removes 636 tons of air pollutants from the atmosphere, valued at $1.5 million. However, this benefit is partially offset because the urban forest emits 246 tons of BVOCs valued at -$0.5 million. As a result, the net annual air quality benefit is $1 million.

These are very conservative estimates of service provided because they do not fully capture all benefits associated with urban tree canopy such as job creation, improved human health and fitness, wildlife habitat, and biodiversity.

Table 31. Ecosystem services (tons unless otherwise specified) provided by the existing urban tree canopy in Marin County.

Jurisdiction	**Heating (MBtu)**	**Cooling (MWh)**	**CO_2 stored**	**CO_2 net sequester**	**CO_2 avoided**	**total CO_2**	**NO_2**	**O_3**	**PM_{10}**	**SO_2**	**Net VOCs (lbs)**	**Interception (1,000 gal)**	**Property value (ac/ac)**
Alto CDP	764	504	1,108.48	69.97	96.38	166.34	0.23	0.30	0.25	0.05	-0.25	1,868	39,183
Belvedere city	5,288	3,537	7,507.06	469.67	677.10	1,146.77	1.54	2.04	1.73	0.33	-1.64	12,665	266,023
Black Point-Green Point CDP	18,337	12,255	33,012.47	2,098.50	2,370.98	4,469.48	6.04	8.32	6.97	1.28	-8.19	51,407	1,029,677
Corte Madera town	14,928	9,703	26,172.18	1,668.90	1,858.57	3,527.47	4.86	6.75	5.63	1.01	-6.76	41,654	854,203
Fairfax town	18,796	12,562	32,883.71	2,085.65	2,430.36	4,516.01	6.10	8.36	7.01	1.30	-8.06	51,626	1,040,238
Kentfield CDP	28,653	19,212	43,303.38	2,718.38	3,676.21	6,394.59	8.61	11.52	9.74	1.86	-9.74	71,502	1,484,021
Lagunitas-Forest Knolls CDP	622	417	2,571.12	166.81	80.56	247.37	0.35	0.56	0.44	0.07	-0.79	3,352	60,540
Larkspur city	16,444	10,881	26,245.85	1,671.23	1,984.88	3,656.11	5.07	7.00	5.85	1.06	-6.12	43,984	916,747
Lucas Valley-Marinwood CDP	10,006	6,808	20,699.59	1,336.67	1,078.07	2,414.74	3.54	5.27	4.30	0.72	-4.89	33,776	687,521
Marin City CDP	1,603	1,078	2,452.74	158.16	151.01	309.17	0.48	0.71	0.58	0.10	-0.47	4,703	103,480
Mill Valley city	34,556	22,852	66,720.70	4,273.53	4,422.05	8,695.57	11.83	16.56	13.79	2.47	-17.33	102,243	2,027,102
Novato city	93,247	62,027	171,173.47	10,898.72	11,964.28	22,863.00	31.06	43.08	35.98	6.55	-43.14	265,893	5,329,416
Ross town	19,165	12,841	25,694.02	1,596.83	2,479.89	4,076.72	5.43	7.08	6.05	1.19	-5.41	43,920	930,295
San Anselmo town	27,229	18,088	38,714.23	2,426.64	3,455.67	5,882.31	7.95	10.55	8.94	1.71	-8.61	65,532	1,382,320
San Geronimo CDP	3,629	2,431	4,856.47	301.79	469.67	771.46	1.03	1.34	1.14	0.23	-1.02	8,306	175,963
San Rafael city	56,203	36,368	132,994.24	8,560.30	6,949.23	15,509.53	21.80	31.95	26.18	4.40	-37.83	195,408	3,842,709
Santa Venetia CDP	3,994	2,694	9,253.49	596.86	489.38	1,086.24	1.52	2.22	1.82	0.31	-2.43	13,845	269,063
Sausalito city	9,651	6,248	16,798.22	1,078.38	1,189.12	2,267.50	3.12	4.34	3.62	0.64	-4.34	26,944	550,376
Sleepy Hollow CDP	13,378	9,138	23,058.87	1,470.34	1,496.72	2,967.06	4.28	6.13	5.07	0.89	-4.94	39,376	822,847
Strawberry CDP	8,089	5,455	12,178.55	777.32	853.80	1,631.12	2.41	3.44	2.84	0.50	-2.40	22,405	485,382
Tamalpais-Homestead Valley CDP	25,528	17,191	44,393.93	2,820.54	3,167.36	5,987.89	8.24	11.44	9.55	1.74	-10.44	71,568	1,458,254
Tiburon town	18,844	12,630	32,908.89	2,089.73	2,353.53	4,443.26	6.10	8.46	7.07	1.29	-7.88	52,728	1,074,141
Unincorporated	40,532	26,779	161,439.73	10,657.20	4,635.68	15,292.89	22.12	35.32	28.18	4.26	-48.80	219,235	3,964,885
Woodacre CDP	11,403	7,610	18,972.08	1,199.31	1,474.11	2,673.42	3.60	4.89	4.12	0.77	-4.56	30,222	615,119
Total	**480,891**	**319,309**	**955,113.46**	**61,191.44**	**59,804.58**	**120,996.02**	**167.30**	**237.62**	**196.87**	**34.73**	**-246.04**	**1,474,162**	**29,409,506**

Table 32. Monetary values of ecosystem service ($1,000) provided by the existing urban tree canopy in Marin County.

Jurisdiction	Heating	Cooling	CO_2 net sequester	CO_2 avoided	total CO_2	NO_2	O_3	PM_{10}	SO_2	Net VOCs	Interception	Property value	Total
Alto CDP	7.29	93.71	0.70	0.96	1.66	0.00	1.03	0.87	0.06	-0.57	10.74	308.67	423.48
Belvedere city	50.43	657.57	4.70	6.77	11.47	0.02	7.00	5.94	0.44	-3.68	72.83	2,206.92	3,008.93
Black Point-Green Point CDP	174.89	2,278.20	20.99	23.71	44.69	0.06	28.59	23.93	1.67	-18.40	295.59	7,695.94	10,525.17
Corte Madera town	142.38	1,803.87	16.69	18.59	35.27	0.05	23.17	19.33	1.32	-15.18	239.51	6,230.69	8,480.42
Fairfax town	179.27	2,335.24	20.86	24.30	45.16	0.06	28.71	24.08	1.69	-18.11	296.85	7,920.88	10,813.83
Kentfield CDP	273.28	3,571.58	27.18	36.76	63.95	0.09	39.56	33.46	2.43	-21.88	411.14	12,031.19	16,404.78
Lagunitas-Forest Knolls CDP	5.94	77.57	1.67	0.81	2.47	0.00	1.91	1.53	0.09	-1.77	19.27	329.63	436.63
Larkspur city	156.83	2,022.84	16.71	19.85	36.56	0.05	24.02	20.09	1.39	-13.74	252.91	6,416.21	8,917.17
Lucas Valley-Marinwood CDP	95.43	1,265.63	13.37	10.78	24.15	0.04	18.09	14.76	0.94	-10.99	194.21	3,612.19	5,214.44
Marin City CDP	15.29	200.34	1.58	1.51	3.09	0.00	2.43	1.99	0.13	-1.05	27.04	507.69	756.95
Mill Valley city	329.58	4,248.27	42.74	44.22	86.96	0.12	56.87	47.35	3.23	-38.94	587.90	14,223.82	19,545.15
Novato city	889.35	11,530.84	108.99	119.64	228.63	0.31	147.92	123.56	8.54	-96.94	1,528.88	39,193.24	53,554.33
Ross town	182.79	2,387.15	15.97	24.80	40.77	0.05	24.32	20.76	1.55	-12.16	252.54	8,102.21	10,999.99
San Anselmo town	259.70	3,362.50	24.27	34.56	58.82	0.08	36.22	30.71	2.23	-19.35	376.81	11,330.58	15,438.29
San Geronimo CDP	34.61	452.01	3.02	4.70	7.71	0.01	4.60	3.93	0.29	-2.30	47.76	1,533.95	2,082.58
San Rafael city	536.04	6,760.76	85.60	69.49	155.10	0.22	109.72	89.90	5.73	-85.01	1,123.60	25,033.50	33,729.55
Santa Venetia CDP	38.09	500.76	5.97	4.89	10.86	0.02	7.63	6.26	0.41	-5.46	79.61	1,612.28	2,250.46
Sausalito city	92.04	1,161.41	10.78	11.89	22.68	0.03	14.90	12.42	0.84	-9.75	154.93	3,799.21	5,248.71
Sleepy Hollow CDP	127.59	1,698.74	14.70	14.97	29.67	0.04	21.06	17.40	1.16	-11.10	226.41	5,011.57	7,122.55
Strawberry CDP	77.15	1,014.04	7.77	8.54	16.31	0.02	11.80	9.76	0.65	-5.39	128.83	2,837.22	4,090.39
Tamalpais-Homestead Valley CDP	243.48	3,195.84	28.21	31.67	59.88	0.08	39.30	32.81	2.28	-23.45	411.52	10,362.45	14,324.18
Tiburon town	179.72	2,347.88	20.90	23.54	44.43	0.06	29.07	24.28	1.68	-17.70	303.18	7,768.98	10,681.59
Unincorporated	386.58	4,978.25	106.57	46.36	152.93	0.22	121.29	96.76	5.56	-109.66	1,260.60	15,119.30	22,011.83
Woodacre CDP	108.75	1,414.64	11.99	14.74	26.73	0.04	16.81	14.14	1.00	-10.25	173.78	4,819.36	6,564.99
Total	**4,586.49**	**59,359.63**	**611.91**	**598.05**	**1,209.96**	**1.67**	**816.01**	**676.04**	**45.31**	**-552.85**	**8,476.43**	**198,007.66**	**272,626.36**

Ecosystem services provided by additional UTC

Planting 212,811 trees will increase UTC from 36.3% to 45.7% once these trees mature approximately 30 years after planting. The additional 9.4% UTC is projected to increase the annual value of ecosystem services (Table 33) by $56 million (Table 34 and Figure 13). The majority of these additional benefits are from increased property values ($41 million, 73%) and energy savings ($12 million, 21%). The calculation assumes that current UTC remains stable and program tree sites remain fully stocked with 30-ft and 50-ft crown diameter trees. Because some program trees will die and need to be replaced, more than 212,811 trees will need to be planted to keep the number of additional sites fully stocked. Additionally, it is conservatively assumed that it will take 30 years to achieve the projected level of canopy cover after planting.

The approximate annual value of ecosystem services provided per tree is $142 for Marin's 1.9 million existing trees plus additional trees and $264 for additional trees alone. The additional trees provide a higher estimated value per tree because of their larger size. Medium and large trees were used in the tree planting scenario, whereas only medium trees were used to estimate existing tree numbers and benefits (McPherson and Simpson 2003, Simpson and McPherson 2001). The average annual benefit of $142 per tree is comparable to results for the same services reported for other cities (Maco et al. 2005). The annual ecosystem service values per acre are approximately $17,000 per acre UTC.

Table 33. Annual property values and ecosystem services (tons unless otherwise specified) provided by the additional canopy at maturity in Marin County.

Jurisdiction	Heating (MBtu)	Cooling (MWh)	CO_2 stored	CO_2 net sequester	CO_2 avoided	total CO_2	NO_2	O_3	PM_{10}	SO_2	Net VOCs (lbs)	Interception (1,000 gal)	Property value (ac/ac)
Alto CDP	132	80	213.82	13.94	16.52	30.46	0.04	0.06	0.05	0.01	-0.06	342	7,015
Belvedere city	450	300	678.88	42.73	56.71	99.44	0.14	0.18	0.15	0.03	-0.15	1,132	23,637
Black Point-Green Point CDP	4,994	3,323	10,231.67	655.48	644.69	1,300.17	1.77	2.50	2.07	0.37	-2.69	15,379	301,426
Corte Madera town	2,586	1,657	7,715.50	499.40	317.30	816.69	1.17	1.77	1.44	0.23	-2.33	10,772	205,973
Fairfax town	1,163	775	2,386.90	152.77	150.26	303.03	0.41	0.58	0.48	0.09	-0.63	3,585	70,292
Kentfield CDP	1,514	1,013	2,978.47	189.75	194.65	384.40	0.52	0.74	0.61	0.11	-0.76	4,539	90,069
Lagunitas-Forest Knolls CDP	548	367	2,738.56	178.10	70.91	249.00	0.36	0.58	0.46	0.07	-0.86	3,477	61,733
Larkspur city	3,874	2,472	5,996.29	385.14	461.33	846.47	1.18	1.62	1.36	0.24	-1.51	10,147	213,844
Lucas Valley-Marinwood CDP	2,370	1,615	5,860.09	381.39	249.35	630.74	0.93	1.43	1.16	0.19	-1.48	9,140	181,034
Marin City CDP	479	289	890.58	59.12	46.32	105.43	0.16	0.24	0.19	0.03	-0.25	1,536	32,598
Mill Valley city	3,173	2,042	9,797.39	641.78	397.66	1,039.44	1.45	2.21	1.79	0.29	-2.96	13,523	250,051
Novato city	29,358	19,334	66,883.93	4,299.84	3,752.29	8,052.13	11.10	16.01	13.20	2.28	-18.47	98,115	1,907,428
Ross town	838	561	1,202.03	74.97	108.32	183.29	0.25	0.32	0.28	0.05	-0.26	2,008	42,097
San Anselmo town	2,748	1,816	4,832.03	306.47	343.09	649.56	0.90	1.24	1.04	0.19	-1.20	7,698	157,884
San Geronimo CDP	253	168	479.68	30.34	32.65	62.99	0.09	0.12	0.10	0.02	-0.12	735	14,781
San Rafael city	12,933	7,533	41,933.90	2,760.31	1,557.97	4,318.29	6.19	9.51	7.66	1.16	-13.98	57,277	1,081,472
Santa Venetia CDP	1,539	1,027	2,986.70	190.33	194.36	384.69	0.53	0.75	0.62	0.11	-0.76	4,608	92,239
Sausalito city	882	527	2,227.80	146.83	106.62	253.45	0.36	0.53	0.43	0.07	-0.71	3,217	62,130
Sleepy Hollow CDP	2,574	1,772	5,488.27	354.66	268.06	622.72	0.93	1.39	1.13	0.19	-1.27	9,002	183,298
Strawberry CDP	2,176	1,475	3,240.18	207.81	210.96	418.77	0.64	0.94	0.77	0.13	-0.59	6,222	136,894
Tamalpais-Homestead Valley CDP	2,447	1,642	4,892.78	314.07	297.58	611.65	0.85	1.22	1.01	0.18	-1.22	7,638	152,428
Tiburon town	5,298	3,550	15,861.36	1,031.27	658.82	1,690.09	2.37	3.60	2.92	0.48	-4.54	22,210	414,305
Unincorporated	15,440	9,395	64,635.37	4,302.57	1,848.09	6,150.66	8.77	13.93	11.12	1.64	-21.10	85,288	1,516,367
Woodacre CDP	1,128	747	2,600.90	166.14	145.45	311.59	0.43	0.62	0.51	0.09	-0.72	3,788	73,996
Total	**98,894**	**63,480**	**266,753.09**	**17,385.21**	**12,129.94**	**29,515.15**	**41.53**	**62.10**	**50.55**	**8.23**	**-78.63**	**381,378**	**7,272,993**

Table 34. Annual monetary values of ecosystem service and property values ($1,000) provided by the additional canopy at maturity in Marin County.

Jurisdiction	Heating	Cooling	CO_2 net sequester	CO_2 avoided	total CO_2	NO_2	O_3	PM_{10}	SO_2	Net VOCs	Interception	Property value	Total
Alto CDP	1.26	14.86	0.14	0.17	0.30	0.00	0.19	0.16	0.01	-0.14	1.97	48.72	67.33
Belvedere city	4.29	55.73	0.43	0.57	0.99	0.00	0.62	0.53	0.04	-0.35	6.51	186.35	254.71
Black Point-Green Point CDP	47.63	617.65	6.55	6.45	13.00	0.02	8.58	7.12	0.48	-6.04	88.43	2,098.52	2,875.38
Corte Madera town	24.66	308.11	4.99	3.17	8.17	0.01	6.09	4.93	0.30	-5.23	61.94	1,230.99	1,639.97
Fairfax town	11.09	144.06	1.53	1.50	3.03	0.00	2.00	1.66	0.11	-1.41	20.61	492.50	673.66
Kentfield CDP	14.44	188.35	1.90	1.95	3.84	0.01	2.53	2.10	0.14	-1.71	26.10	651.07	886.88
Lagunitas-Forest Knolls CDP	5.22	68.27	1.78	0.71	2.49	0.00	1.99	1.58	0.09	-1.94	19.99	314.86	412.56
Larkspur city	36.95	459.55	3.85	4.61	8.46	0.01	5.57	4.66	0.32	-3.40	58.34	1,467.24	2,037.70
Lucas Valley-Marinwood CDP	22.60	300.16	3.81	2.49	6.31	0.01	4.91	3.97	0.24	-3.33	52.56	840.73	1,228.16
Marin City CDP	4.57	53.75	0.59	0.46	1.05	0.00	0.82	0.67	0.04	-0.56	8.83	144.50	213.68
Mill Valley city	30.26	379.60	6.42	3.98	10.39	0.01	7.58	6.14	0.37	-6.66	77.76	1,291.46	1,796.94
Novato city	280.00	3,594.15	43.00	37.52	80.52	0.11	54.99	45.31	2.97	-41.50	564.16	12,743.15	17,323.88
Ross town	7.99	104.36	0.75	1.08	1.83	0.00	1.11	0.95	0.07	-0.59	11.55	358.54	485.80
San Anselmo town	26.21	337.63	3.06	3.43	6.50	0.01	4.27	3.57	0.24	-2.70	44.26	1,173.13	1,593.12
San Geronimo CDP	2.41	31.32	0.30	0.33	0.63	0.00	0.41	0.34	0.02	-0.28	4.22	114.39	153.47
San Rafael city	123.35	1,400.31	27.60	15.58	43.18	0.06	32.66	26.31	1.51	-31.41	329.35	5,674.71	7,600.03
Santa Venetia CDP	14.68	190.99	1.90	1.94	3.85	0.01	2.56	2.13	0.14	-1.71	26.50	655.95	895.10
Sausalito city	8.41	97.92	1.47	1.07	2.53	0.00	1.81	1.48	0.09	-1.59	18.50	337.24	466.40
Sleepy Hollow CDP	24.55	329.46	3.55	2.68	6.23	0.01	4.79	3.89	0.24	-2.85	51.76	909.68	1,327.76
Strawberry CDP	20.75	274.27	2.08	2.11	4.19	0.01	3.22	2.64	0.17	-1.33	35.78	708.28	1,047.97
Tamalpais-Homestead Valley CDP	23.34	305.20	3.14	2.98	6.12	0.01	4.19	3.46	0.23	-2.75	43.92	971.08	1,354.79
Tiburon town	50.53	659.89	10.31	6.59	16.90	0.02	12.37	10.04	0.62	-10.20	127.71	2,235.79	3,103.66
Unincorporated	147.26	1,746.53	43.03	18.48	61.51	0.09	47.85	38.19	2.15	-47.40	490.40	5,574.88	8,061.44
Woodacre CDP	10.75	138.79	1.66	1.45	3.12	0.00	2.14	1.76	0.12	-1.61	21.78	523.83	700.67
Total	**943.20**	**11,800.89**	**173.85**	**121.30**	**295.15**	**0.42**	**213.27**	**173.59**	**10.74**	**-176.69**	**2,192.92**	**40,747.58**	**56,201.07**

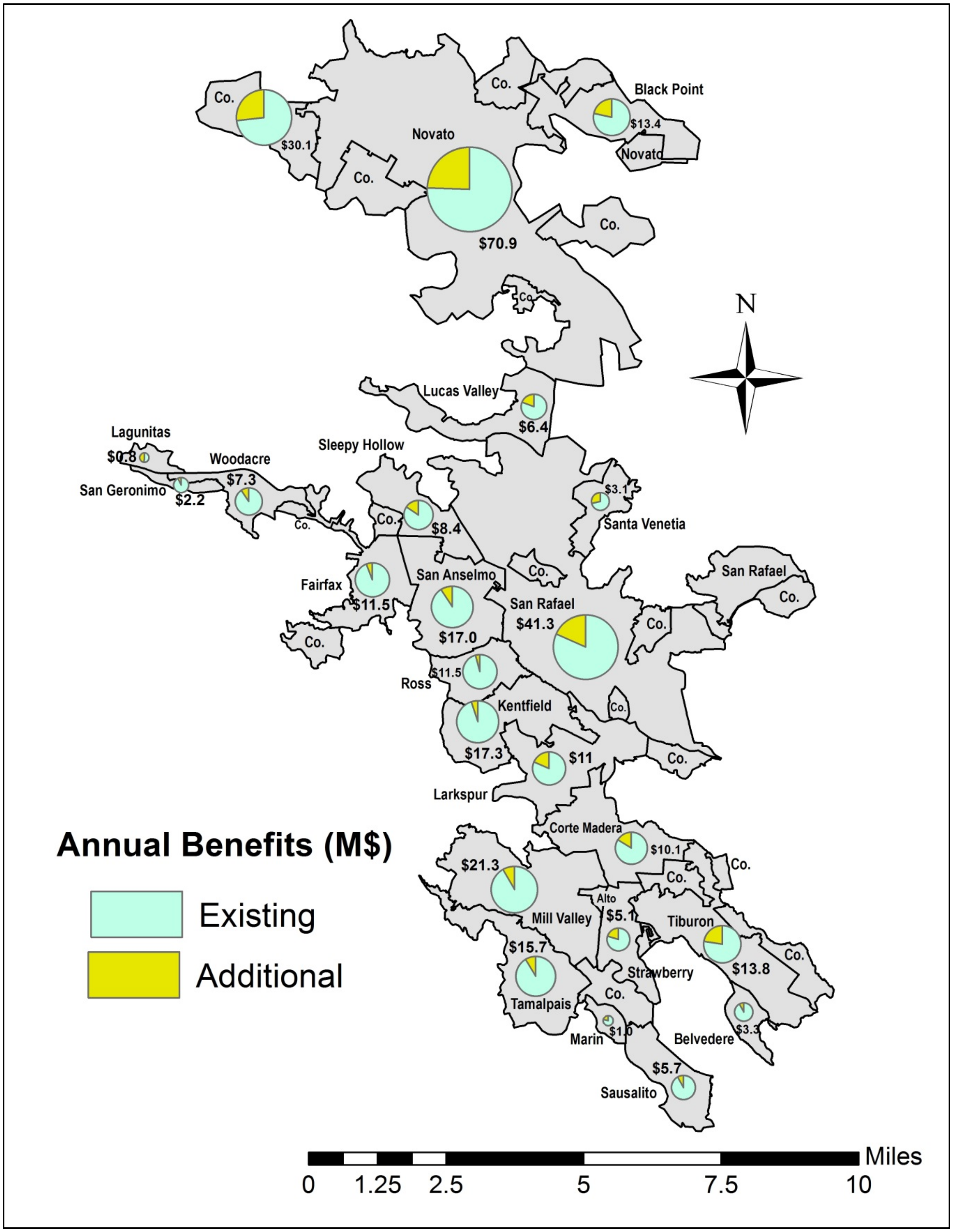


Figure 13. Annual benefits for the existing and additional canopy (M$).

Asset value of Marin's urban forest

The values for ecosystem services have been expressed in annual terms, but trees provide benefits across many generations. Moreover, the benefits trees provide become increasingly scarce and more valuable with time. A benefit derived in 50 years is worth far less than the same benefit today. To enable tree planting and stewardship to be seen as a capital investment, the asset value of trees in Marin was calculated. The annual flows of realized benefits from trees were converted into their net present value, which is a discounted sum of annual future benefits. Discounting future services to their present value incorporates the time value of money and the opportunity cost of investment. The farther ahead in time one goes, the less value a dollar has. By applying this method to the future stream of ecosystem services, the urban forest's asset value is calculated in today's dollars.

The asset value was calculated as the net present value using discount rates of 4.125%, which are used by the US Army Corps of Engineers for large projects, and 0% over 100 years were used for Existing UTC, Additional UTC, and Existing plus Additional UTC. Some economists argue that natural capital has a lower discount rate because the benefit stream is more certain over longer periods of time.

The asset value of Marin's existing urban forest is $6.5 billion, calculated at a 4.125% discount rate for the next 100 years. At a zero discount rate, the urban forest asset value is estimated at $27.3 billion. If UTC is increased from 36.3% to 45.7.3% over the next 30 years by planting 212,811 trees, the urban forest's asset value increases to $7.9 billion and $31.6 billion, assuming 4.125% and 0% discount rates. Hence, the ecosystem services produced by Marin's urban forest provide a stream of benefits over time, just as a freeway or other capital infrastructure does.

Conclusion

Marin's urban forest is extensive, covering 36.3% of the 77 square mile region. Urban tree canopy for the 24 jurisdictions ranged from 20% to 68%. Irrigated grass, bare soil, and dry vegetation covered 25%. Impervious surfaces, such as roads, buildings, and parking lots accounted for 28% of the land area. Of comparable cities, none had a higher percentage of UTC or greenspace (pervious surface). The potential for increased UTC is indicated by the relative amount of greenspace that is not in UTC or stocking level. In 96% of the jurisdictions the stocking level percentages are 70% or more. In all jurisdictions more than 50% of the remaining greenspace is filled by new tree plantings. As a result, their potential for increasing UTC is more limited than it is in other, less forested regions where more greenspace can be converted to UTC.

There are approximately 1.9 million existing trees in Marin County. Cities with the largest number of trees are Novato (350,172), San Rafael (258,146) and Mill Valley (133,999). The average number of trees per acre in Marin is 38.9, which is greater than values reported for San Jose (31.8), Sacramento (21.8) and Los Angeles (19.9). The average number of trees per capita in Marin County is also a relatively high 7.6 compared to values reported for San Jose (3.2), Sacramento (2.8), and Los Angeles (1.6). An abundance of native oaks and associated species that thrive in undisturbed areas may explain the relatively large number of trees per capita, high tree density, and UTC.

Marin's urban forest produces ecosystem services valued at $272.6 million annually. The largest benefit, $198.0 million, is for increased property values and other intangible services. Lowered air temperature from evapotranspirational cooling and building shade reduce residential air condition demand by 319,309 MWh, saving $59.4 million in cooling costs each year. The existing urban forest intercepts 1.5 billion gallons of rainfall that reduces stormwater runoff management costs valued at $8.5 million. If carbon dioxide sequestered and emissions avoided from cooling savings by the existing trees (121,000 tons) were sold at $10 per ton, the revenue would be $1.2 million. Finally, Marin's urban forest filters a net total of 390 tons of air pollutants from the air annually.

Urbanized portions of Marin County contain approximately 425,488 vacant planting sites, with 81% of these in irrigated grass and 19% in bare soil/dry vegetation. This number assumes plantable space for a 30-ft crown diameter tree in irrigated grass and 50-ft tree in bare soil/dry vegetation. Also, it assumes that about 30% of the vacant sites are not plantable because of physical limitations such as utilities.

Setting realistic targets for additional UTC is not straightforward because each jurisdiction has a different land use mix, as well as different existing UTC and potential UTC (PUTC) that reflects historical patterns of development and tree stewardship. After discussing alternative planting scenarios with partners, the research team determined to "plant" 50% of the PTPS in irrigated grass with medium size trees (30-ft crown diameter) and 50% of the PTPS in bare soil/dry vegetation in with large trees (50-ft crown diameter). This scenario resulted in "planting" of 212,811 vacant tree sites; 106,406 with medium trees and the same number with large trees. The targeted number for each jurisdiction was proportional to its number of PTPS, and ranged from 213 to 53,033 trees.

Filling 212,811 additional sites will increase UTC by 9.4%, from 36.3% to 45.7%, once these trees mature, assuming that current UTC remains stable and program tree sites remain fully stocked with mature sized trees. The number of vacant sites to be planted ranges from 213 in Alto to 53,033 in Novato.

Achieving the targeted 9.4% UTC increase will pay dividends. The annual value of ecosystem services and property values will increase by $56.2 million, from $272.6 million to $328.8 million. The worth of increased annual property values and other intangible services is projected to be $40.7 million. Reduced demand for 63,480 MWh of electricity for air conditioning is expected to save another $11.8 million in cooling costs. Annual savings for reduced stormwater management costs from an additional 381.4 million gallons of rainfall interception is projected to be $2.2 million. Trees in the added sites will reduce atmospheric carbon dioxide by 29,515 tons, valued at $295,151 annually. The extra UTC will reduce another 84 tons of pollutants from the air.

Expansion of the UTC from 36.3 to 45.7% is projected to result in provisioning of ecosystem services valued at $328.8 billion annually from approximately 2.1 million trees. The average annual value of $148 per tree is comparable to results for the same services reported for street and park trees in Berkeley (Maco et al. 2005). This is a very conservative estimate of service value, as it does not fully capture all benefits associated with increased UTC, such as job creation, improved human health and fitness, wildlife habitat, and biodiversity.

The asset value of Marin's existing urban forest is $6.5 billion or $3,380 per tree, calculated at a 4.125% discount rate for the next 100 years. At zero discount rate, the region's urban forest asset value is estimated at $27.3 billion. If UTC is increased to 45.7% over the next 30 years, the urban forest's asset value increases to $7.9 billion and $31.6 billion, assuming 4.125% and 0% discount rates, respectively. Hence, the ecosystem services produced by the region's urban forest provides a considerable stream of benefits over time, just as other capital infrastructure does. Quantifying the asset value of this "green infrastructure" can help guide advancement towards a sustainable green economy by shifting investments towards the enhancement of natural capital.

Marin County has many vibrant communities that have invested in their urban forests, both through planting new trees and protecting existing trees from developmental impacts. The task ahead is to better integrate the green infrastructure with the gray infrastructure by targeting tree planting and stewardship activities to maximize their environmental and human health impacts. This study provides information that can be used to plan, prioritize, and implement new urban forestry programs. In so doing, the region's urban forest will become larger, more resilient, and better able to meet the challenges of tomorrow.

Limitations to the study

This study is one of the first to integrate valuation of urban forest services with delineation of UTC. As a pioneering effort it is not surprising that it encountered obstacles and limitations. Future research, development and application are needed to overcome some of these challenges. Several of the most significant limitations are listed.

- Estimates of existing and PTPS are based on field data from previous studies in other California cities because data were lacking for Marin County. Similarly, some transfer functions were based on numerical modeling of tree effects for locations such as Modesto, instead of Marin. Ideally, a study such as this will have access to recently collected field data for more accurate estimation of tree sizes, numbers, and services.
- Estimates of existing and PTPS could be improved through field verification and closer scrutiny of areas unlikely to be planted, such as parks and shorelines. Small trees may have been missed, resulting in overestimates of PTPS, especially in recently developed areas.
- Time gaps between acquisition of remotely sensed data (2011) and field sampling can result in inaccurate land cover maps and benefit estimation. Up-to-date data that overlap spatially and temporally can improve the accuracy of land cover classification and subsequent ecosystem service modeling.
- Lookup tables developed by Dr. Jim Simpson (PSW, now retired) were used to model energy effects. These tables did not include all species found within the study area. Access to more detailed data on energy savings by species and location may also improve the accuracy of ecosystem service results.
- Estimates of ecosystem services are subject to multiple sources of uncertainty. Sampling and measurement error influence the accuracy of data from field plots. Errors are introduced in the derivation, parameterization, and application of numerical models used to estimate effects of trees. For example, annual carbon sequestration estimates are limited by uncertainty inherent in sampling and measurements of trees that were the source of tree growth models. Estimates of avoided emissions rely on a numerical model and multiple sources of error associated with model parameterization and application. Mapping UTC and ecosystem services is subject to errors associated with land cover classification, as well as land use designations. Sensitivity analysis can be used to characterize uncertainty distributions for each type of error, but is beyond the scope of this study.

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Appendix I: Protocol to Calculate Energy Savings

GIS mapping:

2. Identify sample plots by randomly placing points across the map
3. Add 50m buffer to identify plot boundary
4. Identify all buildings that are completely within or intersect with the sample plot
5. Add a 18.3m buffer to these buildings
6. Combine the circular sample plot with the building buffer, this will be the area used for identifying canopy and PTPS
7. Delineate existing canopy (free-hand)
    a. Multiple trees need to be delineated separately
    b. If tree crowns cannot be discerned confidently (e.g. forest) fit 9.1m circles as tightly as possible. Slight overlap (ca. 2m) is allowed between circles.
    c. Since the center of the canopy will be used for calculations, tree canopy and circles can partially be outside the sampling area
8. Identify PTPS using the following criteria:
    a. Use three tree sizes

Tree size	Crown radius (m)	Min. space (soil) requirement (m2)
Large	7.6	9.3
Medium	4.55	3.3
Small	2.3	1.5

    b. Draw large trees first, then medium, then small
    c. Try fitting PTPS with minimal overlap to buildings, other canopy, and areas outside the sampling area (max. ca. 2m)
    d. Minimum distances from tree center:
        i. 0.6m to surrounding impervious pavement
        ii. 5m to surrounding buildings for large trees, 3m for medium trees
        iii. Tree's radius to other tree canopy; slight canopy overlap of ca. 2m allowed for medium and large trees
    e. No large or medium trees within 5m of an intersection
    f. No medium or large trees under power lines or other infrastructure that would impede tree growth in the long term
    g. No small trees closely surrounded by existing medium or large trees

GIS calculation:

2. Existing trees: Identify center point of canopy polygons (feature to center tool); create a new layer
    a. Add a CanopyID by copying the objectID into a new column. Make sure the field you create is long
    b. Add two more fields (double) for X and Y coordinates; use calculate geometry to add the coordinates
    c. Add a field and calculate the area of each polygon; crown projection (calculate geometry)
3. PTPS: Identify center point of canopy polygons (feature to center tool); create a new layer
    a. Add a PTPSID by copying the objectID into a new column. Make sure the field you create is long
    b. Add two more fields (double) for X and Y coordinates; use calculate geometry to add the coordinates
    c. Add a field and calculate the area of each polygon; crown projection (calculate geometry)
4. Building data: use 'feature to point' tool to identify building centroid
5. Calculate azimuth of canopy and PTPS to surrounding building centroids, distance 100m (name new table CanopyAzimuth or PTPSAzimuth)
    a. Add column to each table called In_Plus_NearFID, use field calculator to combine In_FID & Near_FID
    b. Add a field called 'Azimuth_Class' and apply the script below
6. Calculate distance of canopy and PTPS to surrounding buildings (18.3m) using the building (polygon) layer (name new tables CanopyDistance or PTPSDistance)
    a. Add column to each table called In_Plus_NearFID, use field calculator to combine In_FID & Near_FID
    b. Add a field called 'Distance_Class' and apply script below
7. Join Distance table to Canopy and PTPS table, respectively, using IN_FID from the Distance table and ObjectID12 from Canopy and PTPS table
8. Join newly created join table with Azimuth table using In_Plus_NearFID column
9. Export tables and import them again to delete unwanted columns, then create a shapefile based on the earlier created X and Y coordinates
10. Now you should have one table for existing trees and one for PTPS that include their crown diameter, azimuth, and distance class
11. Select all trees from the original Canopy layer that are not within the created existing canopy layer (reverse selection)

   a. Export the result, these trees are outside 18.3m of buildings and thus only provide a climate effect for energy TFs (name Canopy_Clim)
12. Select all PTPS from the original PTPS layer that are not within the created existing canopy layer (reverse selection)
   a. Export the result, these PTPS are outside 18.3m of buildings and thus only provide a climate effect for energy TFs (name PTPS_Clim)
13. For all tables, calculate DBH classes for the following three species based on previous tree inventories:
   a. Deciduous broadleaf: *Platanus hybrida* (PLAC), plane tree
      → DBH (cm)= 0.281504*Crown Projection (m^2) + 5.484907
   b. Evergreen broadleaf: *Magnolia grandiflora* (MAGR), Southern magnolia
      → DBH (cm)= 0.449436617*Crown Projection (m^2)+5.099417809 (based on Berkeley inventory data)
   c. Evergreen needleleaf: *Pinus radiata* (PIRA), Monterey pine
      → DBH (cm) =0.408288698* Crown Projection (m^2) + 13.3314855
14. You should now have two existing tree tables and two for PTPS, one each within and outside 18.3m.

<u>TFs compilation</u>

1. For each of the four tables (Canopy & PTPS within 18.3m and Canopy & PTPS outside 18.3m) use Simpson' lookup tables of the appropriate location; Santa Rosa, San Jose, Fort Collins to compile RU's
2. Existing trees within 18.3m of buildings: locate the heating and cooling TFs for each tree for all three tree species (see 10.) depending on size, distance class, and azimuth, as well as the clim effect in separate columns. These will be summed up later.
3. PTPS within 18.3m of buildings: : locate the heating and cooling TFs for each tree for all three tree species (see 10.) depending on size, distance class, and azimuth, as well as the clim effect (will be summed up later)
4. Locate the clim effects (heating and cooling) for each tree in the Canopy_Clim table for all three species (see 10.)
5. Locate the clim effects (heating and cooling) for each tree in the PTPS_Clim table for all three species (see 10.)
6. Identify if there are any buildings with only one tree within 18.3m. Subtract 5% from the total cooling and heating effects for <u>all other trees</u>.
7. For tree-building relationships in the multi-family residential zoning class apply a 0.74 potential shading adjustment factor as well as a 0.8 potential climate adjustment factor to the to the energy savings values from Simpson's lookup tables.

Tree ID	Tree Species							
	Cool	**Heat**	**Cool clim**	**Heat clim**	**Cool Total**	**Heat total**	**Cool total adjusted**	**Heat total adjusted**
	Location effect of tree within 18.3m		Clim effect of that tree		Sum of location and clim effect		Sum * 0.95 for all trees that share a building (within 18.3m)	

Table 35. Energy templates on a per tree basis for plane tree separated by model tree species and vintages.

Average cooling ($0.186/kWh) and heating ($0.00954/kBTU) effect per tree for a medium sized (30-ft diameter) broadleaf, decidious, *Platanus occidentalis* (plane tree) divided by building vintage class.

Data are for structures built pre-1950.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	277.0	51.49	243.9	2.33	277.0	51.49	243.9	2.33	277.0	51.49	243.9	2.33	277.0	51.49	243.9	2.33
NE	284.0	52.80	223.9	2.14	278.0	51.68	239.9	2.29	277.0	51.49	243.9	2.33	277.0	51.49	243.9	2.33
E	535.0	99.46	-169.1	-1.61	406.0	75.48	-233.1	-2.22	317.0	58.93	-131.1	-1.25	277.0	51.49	243.9	2.33
SE	476.0	88.49	52.9	0.50	352.0	65.44	49.9	0.48	295.0	54.84	76.9	0.73	277.0	51.49	243.9	2.33
S	604.0	112.28	-268.1	-2.56	359.0	66.74	-37.1	-0.35	283.0	52.61	189.9	1.81	277.0	51.49	243.9	2.33
SW	500.0	92.95	2.9	0.03	368.0	68.41	18.9	0.18	303.0	56.33	98.9	0.94	277.0	51.49	243.9	2.33
W	818.0	152.07	16.9	0.16	591.0	109.87	101.9	0.97	394.0	73.24	166.9	1.59	277.0	51.49	243.9	2.33
NW	281.0	52.24	243.9	2.33	277.0	51.49	243.9	2.33	277.0	51.49	243.9	2.33	277.0	51.49	243.9	2.33

Data are for structures built between 1950 and 1980.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	275.0	51.12	176.9	1.69	275.0	51.12	176.9	1.69	275.0	51.12	176.9	1.69	275.0	51.12	176.9	1.69
NE	282.0	52.42	159.9	1.53	277.0	51.49	171.9	1.64	275.0	51.12	176.9	1.69	275.0	51.12	176.9	1.69
E	524.0	97.41	-204.1	-1.95	413.0	76.78	-310.1	-2.96	317.0	58.93	-229.1	-2.19	275.0	51.12	176.9	1.69
SE	469.0	87.19	39.9	0.38	355.0	65.99	39.9	0.38	300.0	55.77	52.9	0.50	275.0	51.12	176.9	1.69
S	587.0	109.12	-176.1	-1.68	372.0	69.15	-21.1	-0.20	285.0	52.98	132.9	1.27	275.0	51.12	176.9	1.69
SW	573.0	106.52	-25.1	-0.24	395.0	73.43	-37.1	-0.35	313.0	58.19	27.9	0.27	275.0	51.12	176.9	1.69
W	736.0	136.82	32.9	0.31	577.0	107.26	84.9	0.81	406.0	75.48	127.9	1.22	275.0	51.12	176.9	1.69
NW	279.0	51.87	175.9	1.68	275.0	51.12	176.9	1.69	275.0	51.12	176.9	1.69	275.0	51.12	176.9	1.69

Data are for structures built post-1980.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	199.0	36.99	108.8	1.04	199.0	36.99	108.8	1.04	199.0	36.99	108.8	1.04	199.0	36.99	108.8	1.04
NE	206.0	38.30	69.8	0.67	200.0	37.18	104.8	1.00	199.0	36.99	108.8	1.04	199.0	36.99	108.8	1.04
E	354.0	65.81	-407.2	-3.88	268.0	49.82	-440.2	-4.20	217.0	40.34	-269.2	-2.57	199.0	36.99	108.8	1.04
SE	330.0	61.35	-38.2	-0.36	226.0	42.01	3.8	0.04	203.0	37.74	26.8	0.26	199.0	36.99	108.8	1.04
S	417.0	77.52	-43.2	-0.41	237.0	44.06	62.8	0.60	202.0	37.55	106.8	1.02	199.0	36.99	108.8	1.04
SW	437.0	81.24	1.8	0.02	274.0	50.94	14.8	0.14	215.0	39.97	52.8	0.50	199.0	36.99	108.8	1.04
W	562.0	104.48	31.8	0.30	408.0	75.85	58.8	0.56	279.0	51.87	77.8	0.74	199.0	36.99	108.8	1.04
NW	216.0	40.15	107.8	1.03	199.0	36.99	108.8	1.04	199.0	36.99	108.8	1.04	199.0	36.99	108.8	1.04

Table 36. Energy templates on a per tree basis for Southern magnolia separated by model tree species and vintages

Average cooling ($0.186/kWh) and heating ($0.00954/kBTU) effect per tree for a medium sized (30-ft diameter) broadleaf, evergreen, *Magnolia grandiflora* (Southern magnolia) divided by building vintage class.

Data are for structures built pre-1950.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	299.0	55.58	242.9	2.32	299.0	55.58	242.9	2.32	299.0	55.58	242.9	2.32	299.0	55.58	242.9	2.32
NE	307.0	57.07	220.9	2.11	301.0	55.96	238.9	2.28	299.0	55.58	242.9	2.32	299.0	55.58	242.9	2.32
E	560.0	104.10	-176.1	-1.68	437.0	81.24	-222.1	-2.12	352.0	65.44	-144.1	-1.37	299.0	55.58	242.9	2.32
SE	509.0	94.62	-31.1	-0.30	390.0	72.50	-70.1	-0.67	324.0	60.23	-63.1	-0.60	299.0	55.58	242.9	2.32
S	654.0	121.58	-689.1	-6.57	416.0	77.33	-394.1	-3.76	311.0	57.81	62.9	0.60	299.0	55.58	242.9	2.32
SW	546.0	101.50	-156.1	-1.49	408.0	75.85	-179.1	-1.71	335.0	62.28	-79.1	-0.75	299.0	55.58	242.9	2.32
W	824.0	153.18	-54.1	-0.52	638.0	118.60	87.9	0.84	435.0	80.87	164.9	1.57	299.0	55.58	242.9	2.32
NW	303.0	56.33	241.9	2.31	299.0	55.58	242.9	2.32	299.0	55.58	242.9	2.32	299.0	55.58	242.9	2.32

Data are for structures built between 1950 and 1980.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	299.0	55.58	174.9	1.67	299.0	55.58	174.9	1.67	299.0	55.58	174.9	1.67	299.0	55.58	174.9	1.67
NE	306.0	56.89	155.9	1.49	301.0	55.96	169.9	1.62	300.0	55.77	174.9	1.67	299.0	55.58	174.9	1.67
E	539.0	100.20	-198.1	-1.89	437.0	81.24	-290.1	-2.77	351.0	65.25	-240.1	-2.29	299.0	55.58	174.9	1.67
SE	499.0	92.76	-4.1	-0.04	392.0	72.87	-52.1	-0.50	329.0	61.16	-62.1	-0.59	299.0	55.58	174.9	1.67
S	628.0	116.75	-453.1	-4.32	422.0	78.45	-262.1	-2.50	319.0	59.30	43.9	0.42	299.0	55.58	174.9	1.67
SW	612.0	113.77	-141.1	-1.35	444.0	82.54	-189.1	-1.80	349.0	64.88	-112.1	-1.07	299.0	55.58	174.9	1.67
W	746.0	138.68	-17.1	-0.16	614.0	114.14	71.9	0.69	444.0	82.54	124.9	1.19	299.0	55.58	174.9	1.67
NW	305.0	56.70	173.9	1.66	299.0	55.58	174.9	1.67	299.0	55.58	174.9	1.67	299.0	55.58	174.9	1.67

Data are for structures built post-1980.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	214.0	39.78	107.8	1.03	214.0	39.78	107.8	1.03	214.0	39.78	107.8	1.03	214.0	39.78	107.8	1.03
NE	222.0	41.27	67.8	0.65	215.0	39.97	102.8	0.98	214.0	39.78	107.8	1.03	214.0	39.78	107.8	1.03
E	365.0	67.85	-400.2	-3.82	292.0	54.28	-429.2	-4.09	237.0	44.06	-303.2	-2.89	214.0	39.78	107.8	1.03
SE	348.0	64.69	-99.2	-0.95	248.0	46.10	-90.2	-0.86	221.0	41.08	-72.2	-0.69	214.0	39.78	107.8	1.03
S	447.0	83.10	-215.2	-2.05	270.0	50.19	-27.2	-0.26	219.0	40.71	94.8	0.90	214.0	39.78	107.8	1.03
SW	463.0	86.07	-89.2	-0.85	304.0	56.51	-88.2	-0.84	238.0	44.24	-30.2	-0.29	214.0	39.78	107.8	1.03
W	567.0	105.41	6.8	0.06	437.0	81.24	53.8	0.51	309.0	57.44	75.8	0.72	214.0	39.78	107.8	1.03
NW	233.0	43.31	105.8	1.01	214.0	39.78	107.8	1.03	214.0	39.78	107.8	1.03	214.0	39.78	107.8	1.03

Table 37. Energy templates on a per tree basis for Monterey pine, separated by model tree species and vintages

Average cooling ($0.186/kWh) and heating ($0.00954/kBTU) effect per tree for a medium sized (30-ft diameter) conifer, *Pinus radiata* (Monterey pine) divided by building vintage class.

Data are for structures built pre-1950.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	279.0	51.87	243.9	2.33	279.0	51.87	243.9	2.33	279.0	51.87	243.9	2.33	279.0	51.87	243.9	2.33
NE	285.0	52.98	223.9	2.14	280.0	52.05	239.9	2.29	285.0	52.98	239.9	2.29	279.0	51.87	243.9	2.33
E	551.0	102.43	-89.1	-0.85	436.0	81.05	-185.1	-1.77	551.0	102.43	-185.1	-1.77	279.0	51.87	243.9	2.33
SE	500.0	92.95	10.9	0.10	386.0	71.76	-42.1	-0.40	500.0	92.95	-42.1	-0.40	279.0	51.87	243.9	2.33
S	661.0	122.88	-530.1	-5.06	421.0	78.26	-442.1	-4.22	661.0	122.88	-442.1	-4.22	279.0	51.87	243.9	2.33
SW	548.0	101.87	-112.1	-1.07	415.0	77.15	-163.1	-1.56	548.0	101.87	-163.1	-1.56	279.0	51.87	243.9	2.33
W	816.0	151.69	9.9	0.09	654.0	121.58	110.9	1.06	816.0	151.69	110.9	1.06	279.0	51.87	243.9	2.33
NW	279.0	51.87	242.9	2.32	279.0	51.87	243.9	2.33	279.0	51.87	243.9	2.33	279.0	51.87	243.9	2.33

Data are for structures built between 1950 and 1980.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	277.0	51.49	175.9	1.68	277.0	51.49	175.9	1.68	277.0	51.49	4.0	0.04	277.0	51.49	175.9	1.68
NE	283.0	52.61	157.9	1.51	280.0	52.05	171.9	1.64	278.0	51.68	4.0	0.04	277.0	51.49	175.9	1.68
E	525.0	97.60	-107.1	-1.02	437.0	81.24	-246.1	-2.35	348.0	64.69	-434.0	-4.14	277.0	51.49	175.9	1.68
SE	481.0	89.42	30.9	0.29	385.0	71.57	-18.1	-0.17	317.0	58.93	-230.0	-2.19	277.0	51.49	175.9	1.68
S	624.0	116.00	-295.1	-2.81	423.0	78.64	-282.1	-2.69	307.0	57.07	-172.0	-1.64	277.0	51.49	175.9	1.68
SW	595.0	110.61	-87.1	-0.83	447.0	83.10	-168.1	-1.60	344.0	63.95	-321.0	-3.06	277.0	51.49	175.9	1.68
W	715.0	132.92	21.9	0.21	618.0	114.89	90.9	0.87	463.0	86.07	-45.0	-0.43	277.0	51.49	175.9	1.68
NW	278.0	51.68	175.9	1.68	277.0	51.49	175.9	1.68	277.0	51.49	4.0	0.04	277.0	51.49	175.9	1.68

Data are for structures built post-1980.

Azimuth	Distance Class 1 (<20ft)				Distance Class 2 (20-40ft)				Distance Class 3 (40-60ft)				Distance Class 4 (>60ft= climate only effect)			
	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)	cooling (kWh)	cooling ($)	heating (kBTU)	heating ($)
N	201.0	37.37	108.8	1.04	201.0	37.37	108.8	1.04	201.0	37.37	4.0	0.04	201.0	37.37	108.8	1.04
NE	206.0	38.30	77.8	0.74	202.0	37.55	103.8	0.99	201.0	37.37	4.0	0.04	201.0	37.37	108.8	1.04
E	358.0	66.55	-334.2	-3.19	295.0	54.84	-414.2	-3.95	233.0	43.31	-463.0	-4.42	201.0	37.37	108.8	1.04
SE	339.0	63.02	-63.2	-0.60	245.0	45.55	-73.2	-0.70	214.0	39.78	-184.0	-1.75	201.0	37.37	108.8	1.04
S	455.0	84.58	-173.2	-1.65	273.0	50.75	-38.2	-0.36	210.0	39.04	-21.0	-0.20	201.0	37.37	108.8	1.04
SW	457.0	84.96	-64.2	-0.61	313.0	58.19	-85.2	-0.81	235.0	43.69	-155.0	-1.48	201.0	37.37	108.8	1.04
W	561.0	104.29	18.8	0.18	457.0	84.96	57.8	0.55	328.0	60.98	-30.0	-0.29	201.0	37.37	108.8	1.04
NW	212.0	39.41	107.8	1.03	201.0	37.37	108.8	1.04	201.0	37.37	4.0	0.04	201.0	37.37	108.8	1.04

Appendix II: Sample data by census block group

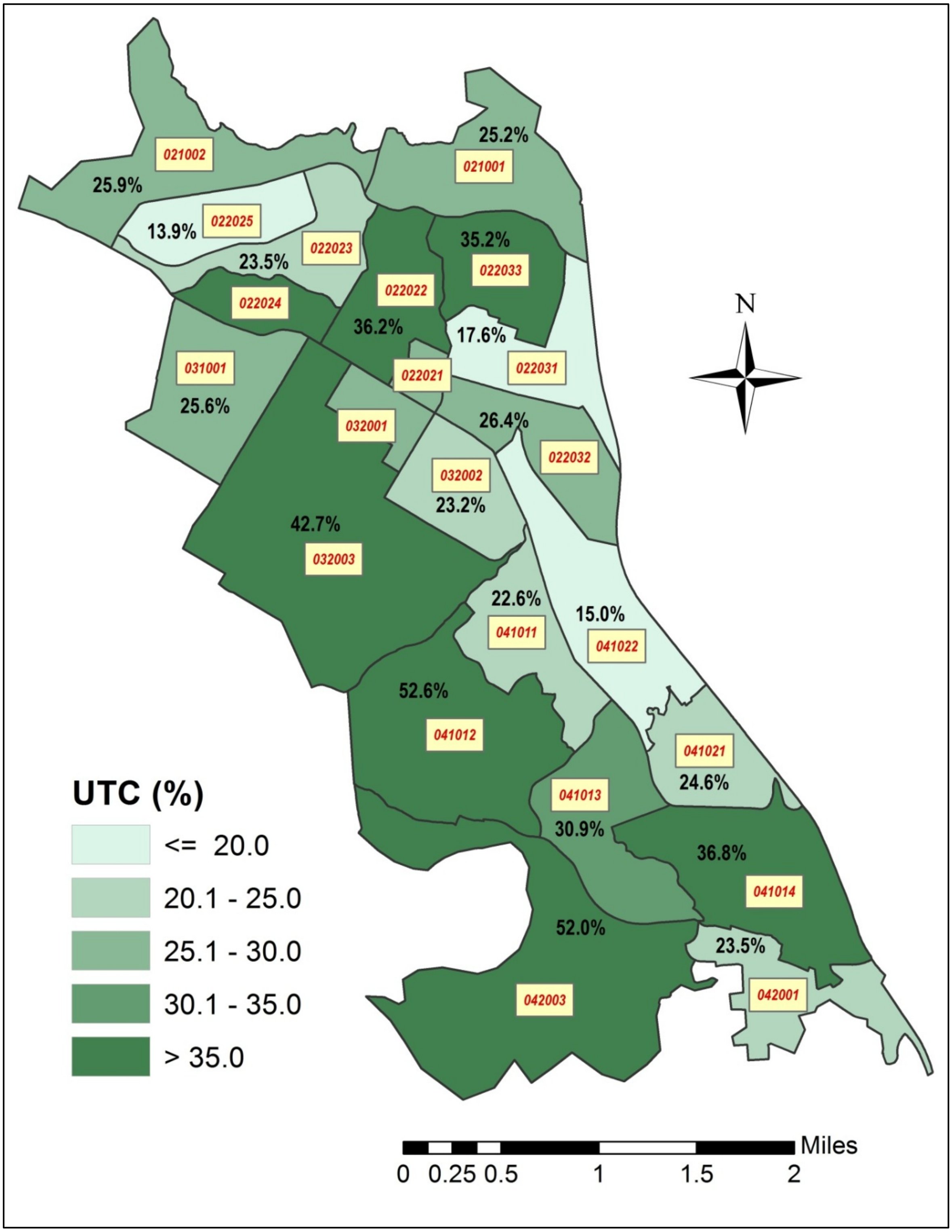

Figure 14. Appendix II Example of UTC (%) by census block group.

Table 38. Appendix II: Example of potential tree planting sites (acres) by census block group.

Census Block Group	Tree	Shrub	Irrigated Grass	Dry Grass	Building	Water	Impervious	Project Area	Total CBG Area	% Area	No. Existing Trees	PTPS Irrigated Grass	PTPS Dry Grass
060411011	1,040	97	542	308	69	41	196	2,292	8,597	27	111,360	58,027	10,666
060411012	353	60	316	279	85	71	231	1,396	2,618	53	37,849	33,881	9,686
060411021	84	12	47	91	23	1	73	331	967	34	8,952	5,033	3,139
060411021	100	17	54	88	36	0	90	385	1,392	28	10,727	5,785	3,034
060411022	11	1	5	3	8	1	14	42	42	100	1,175	568	92
060411022	83	10	30	50	22	1	34	230	230	100	8,912	3,179	1,742
060411022	49	11	28	22	38	1	60	209	209	100	5,278	2,991	774
060411022	50	5	16	16	12	1	19	119	119	100	5,388	1,685	552
060411022	25	8	26	31	33	0	58	181	181	100	2,700	2,773	1,063
060411022	40	13	28	32	33	0	81	227	227	100	4,288	2,983	1,120
060411022	60	13	24	30	35	1	63	225	225	100	6,379	2,561	1,025
060411022	78	12	24	55	23	0	29	221	221	100	8,331	2,547	1,898
060411031	75	17	36	30	53	1	79	291	291	100	8,004	3,826	1,025
060411031	312	67	218	300	39	220	109	1,264	7,904	16	33,420	23,351	10,404
060411031	596	53	72	156	55	7	110	1,048	1,827	57	63,850	7,703	5,404
060411031	63	13	24	21	37	0	49	208	208	100	6,802	2,546	745
060411032	24	3	15	7	17	1	21	88	88	100	2,567	1,599	240
060411032	45	10	29	19	44	1	47	195	195	100	4,871	3,137	647
060411032	373	41	114	175	63	6	100	873	873	100	39,953	12,248	6,072
060411041	52	11	32	30	43	0	61	228	228	100	5,542	3,392	1,051
060411041	276	23	24	105	35	0	61	523	523	100	29,524	2,555	3,627
060411041	95	20	25	57	44	0	67	308	308	100	10,213	2,628	1,981
060411041	153	16	42	76	35	0	92	415	415	100	16,380	4,550	2,631
060411041	48	7	25	41	25	0	47	193	193	100	5,090	2,697	1,413
060411041	51	13	76	42	40	15	100	337	337	100	5,452	8,190	1,445
060411042	53	12	30	18	37	0	76	226	473	48	5,698	3,228	625
....	....	...	...	...	...	...	...	...	...	...	...	...	...

Table 39. Appendix II: Example of ecosystem services (tons unless otherwise specified) by census block group.

Census Block Group	Heating (MBtus)	Cooling (MWhs)	CO2 stored	CO2 net sequester	CO2 avoided	total CO2	NO2	O3	PM10	SO2	Net VOCs	Interception (1,000gal)	Property Value (ac/ac)
060411011001	20,164	13,481	63,997	4,173	2,605	6,778	9.4	14.3	11.6	1.9	-18.7	87,397	1,594,822
060411012001	7,026	4,626	21,442	1,398	904	2,302	3.2	4.8	3.9	0.6	-6.3	29,468	542,699
060411021001	1,402	828	5,261	351	172	523	0.7	1.1	0.9	0.1	-1.7	6,998	125,394
060411021002	3,555	2,383	4,617	286	460	746	1.0	1.3	1.1	0.2	-0.9	7,981	169,861
060411022021	202	113	613	41	20	61	0.1	0.1	0.1	0.0	-0.2	900	17,793
060411022022	2,953	1,980	3,836	238	382	620	0.8	1.1	0.9	0.2	-0.8	6,630	141,114
060411022023	1,748	1,172	2,272	141	226	367	0.5	0.6	0.5	0.1	-0.5	3,927	83,563
060411022024	1,571	1,053	2,494	156	203	360	0.5	0.7	0.6	0.1	-0.6	4,028	83,167
060411022025	831	557	1,214	76	108	183	0.2	0.3	0.3	0.1	-0.3	2,015	42,113
060411022031	1,370	843	1,833	118	173	291	0.4	0.5	0.4	0.1	-0.5	3,122	66,388
060411022032	2,055	1,317	2,748	174	263	437	0.6	0.8	0.6	0.1	-0.7	4,688	99,576
060411022033	2,758	1,849	3,588	223	357	580	0.8	1.0	0.9	0.2	-0.7	6,199	131,898
060411031001	2,221	1,481	3,790	239	287	526	0.7	1.0	0.8	0.2	-0.9	5,986	122,310
060411031002	4,489	3,028	20,540	1,352	555	1,908	2.7	4.4	3.5	0.5	-6.3	26,785	470,166
060411031003	3,391	2,330	44,205	2,959	360	3,319	4.9	8.6	6.7	0.9	-14.7	52,950	854,327
060411031004	2,254	1,511	2,928	182	292	473	0.6	0.8	0.7	0.1	-0.6	5,061	107,709
060411032001	851	570	1,105	69	110	179	0.2	0.3	0.3	0.1	-0.2	1,910	40,652
060411032002	1,583	1,067	2,085	130	198	327	0.4	0.6	0.5	0.1	-0.4	3,681	78,902
060411032003	8,362	5,606	21,909	1,418	1,082	2,500	3.4	5.1	4.1	0.7	-6.1	31,078	583,451
060411041011	1,703	1,132	2,486	156	219	375	0.5	0.7	0.6	0.1	-0.6	4,143	86,608
060411041012	9,719	6,516	12,770	793	1,258	2,051	2.7	3.5	3.0	0.6	-2.6	21,983	466,832
060411041013	3,384	2,269	4,396	273	438	711	0.9	1.2	1.0	0.2	-0.9	7,599	161,720
060411041014	5,324	3,564	7,130	443	688	1,132	1.5	2.0	1.7	0.3	-1.5	12,200	258,425
060411041021	1,666	1,117	2,208	137	216	353	0.5	0.6	0.5	0.1	-0.5	3,789	80,394
060411041022	1,546	978	2,519	161	196	358	0.5	0.7	0.6	0.1	-0.7	4,030	83,032
060411042001	1,820	1,224	2,477	154	229	384	0.5	0.7	0.6	0.1	-0.5	4,291	91,283
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Table 40. Appendix II: Example of monetary values ($) of ecosystem services by census block group.

Census Block Group	Heating	Cooling	CO_2 net sequester	CO_2 avoided	total CO_2	NO_2	O_3	PM_{10}	SO_2	Net VOCs	Interception	Property Value	Total
060411011001	192,316	2,506,074	41,728	26,051	67,779	94	48,948	39,710	2,466	-42,114	502,532	8,493,279	11,811,084
060411012001	67,013	859,904	13,978	9,043	23,021	32	16,544	13,441	835	-14,247	169,443	2,977,547	4,113,532
060411021001	13,372	153,967	3,509	1,717	5,226	7	3,942	3,164	180	-3,924	40,240	493,477	709,651
060411021002	33,903	443,025	2,864	4,601	7,465	10	4,414	3,777	284	-2,132	45,892	1,495,546	2,032,184
060411022021	1,927	20,914	409	196	605	1	500	399	21	-460	5,178	71,523	100,609
060411022022	28,166	368,063	2,379	3,823	6,202	8	3,667	3,138	236	-1,771	38,125	1,242,472	1,688,305
060411022023	16,675	217,901	1,409	2,263	3,672	5	2,171	1,858	140	-1,050	22,578	735,637	999,589
060411022024	14,981	195,761	1,563	2,033	3,596	5	2,244	1,894	136	-1,303	23,163	686,985	927,461
060411022025	7,923	103,534	758	1,075	1,833	2	1,119	950	70	-606	11,584	357,297	483,706
060411022031	13,066	156,632	1,179	1,730	2,909	4	1,747	1,487	104	-1,119	17,950	520,635	713,416
060411022032	19,602	244,846	1,739	2,627	4,366	6	2,612	2,227	161	-1,501	26,955	825,808	1,125,082
060411022033	26,309	343,785	2,225	3,571	5,796	8	3,428	2,934	221	-1,658	35,642	1,160,777	1,577,241
060411031001	21,182	275,290	2,387	2,870	5,257	7	3,346	2,809	198	-2,081	34,420	980,789	1,321,218
060411031002	42,817	562,973	13,524	5,553	19,077	27	14,975	11,935	689	-14,175	154,015	1,868,956	2,661,290
060411031003	32,344	433,226	29,587	3,601	33,188	49	29,642	22,979	1,160	-33,034	304,460	1,215,853	2,039,867
060411031004	21,498	280,926	1,816	2,918	4,734	6	2,799	2,395	180	-1,352	29,100	948,336	1,288,623
060411032001	8,114	106,028	685	1,101	1,787	2	1,056	904	68	-510	10,983	357,924	486,357
060411032002	15,099	198,284	1,298	1,976	3,274	4	2,011	1,710	126	-928	21,165	646,372	887,116
060411032003	79,751	1,042,149	14,181	10,824	25,005	34	17,361	14,223	919	-13,752	178,696	3,517,978	4,862,364
060411041011	16,244	210,512	1,560	2,185	3,745	5	2,296	1,947	142	-1,266	23,821	713,130	970,576
060411041012	92,691	1,211,247	7,928	12,580	20,508	27	12,159	10,398	781	-5,945	126,405	4,088,799	5,557,071
060411041013	32,280	421,815	2,726	4,381	7,107	9	4,202	3,596	271	-2,030	43,692	1,423,919	1,934,862
060411041014	50,778	662,523	4,435	6,881	11,316	15	6,752	5,765	430	-3,380	70,149	2,241,796	3,046,144
060411041021	15,891	207,662	1,371	2,157	3,527	5	2,097	1,792	134	-1,034	21,786	703,510	955,372
060411041022	14,749	181,730	1,613	1,965	3,578	5	2,260	1,899	131	-1,531	23,171	630,288	856,279
060411042001	17,356	227,624	1,544	2,294	3,838	5	2,355	2,001	147	-1,145	24,671	754,275	1,031,127
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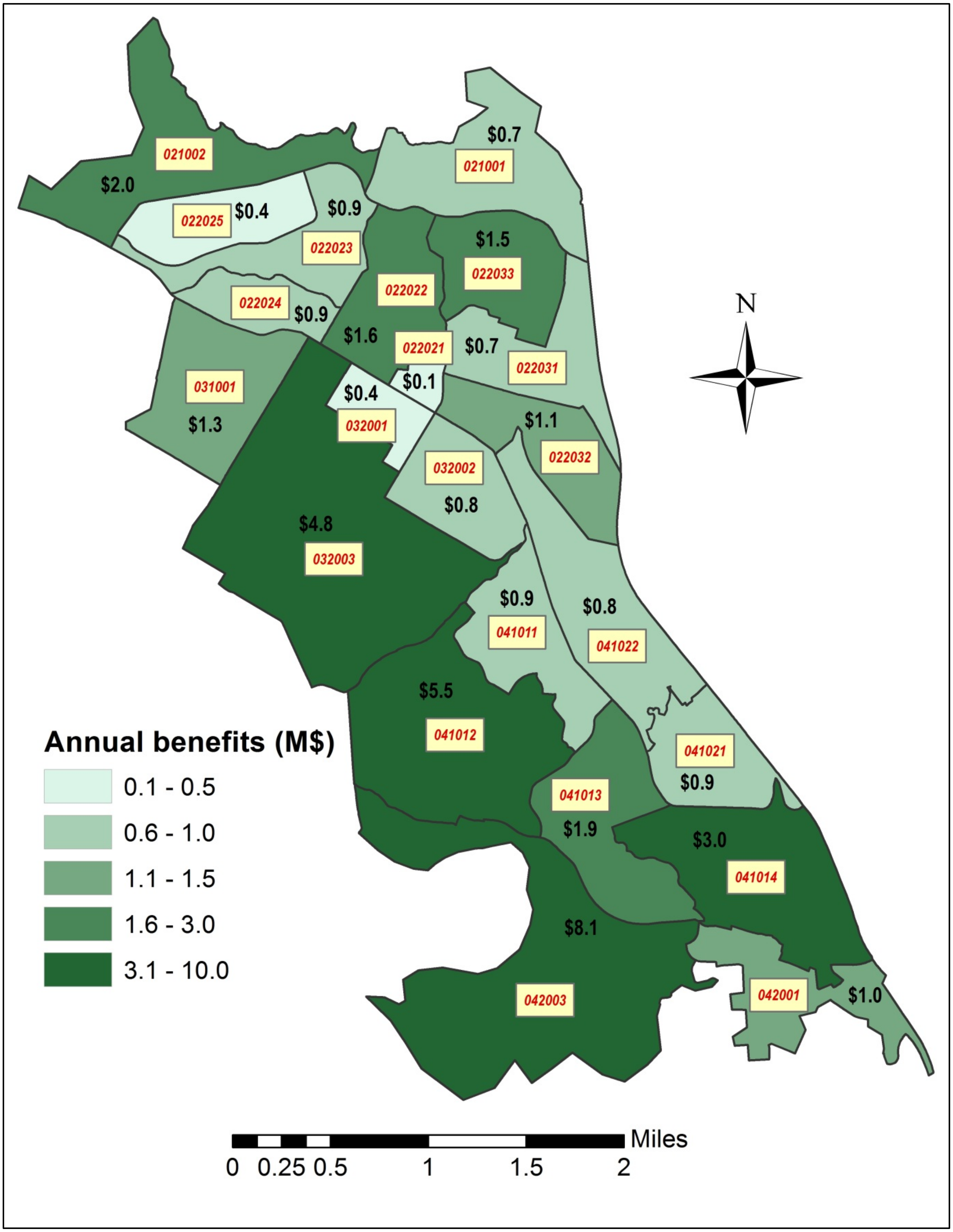

Figure 15. Appendix II: Example of annual benefits (M$) census block group.