USDA

United States
Department of
Agriculture

Forest Service

**Northern
Research Station**

Resource Bulletin NRS-8

Assessing Urban Forest Effects and Values

San Francisco's Urban Forest

Northern
RESEARCH STATION
USDA Forest Service

UFORE
Urban Forest Effects Model

Abstract

An analysis of trees in San Francisco, CA reveals that this city has about 669,000 trees with canopies that cover 11.9 percent of the area. The most common tree species are blue gum eucalyptus, Monterey pine, and Monterey cypress. The urban forest currently stores about 196,000 tons of carbon valued at $3.6 million. In addition, these trees remove about 5,200 tons of carbon per year ($95,000 per year) and about 260 tons of air pollution per year ($1.3 million per year). The structural, or compensatory, value is estimated at $1.7 billion. Information on the structure and functions of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the San Francisco area.

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Acknowledgments

We are grateful for the contributions of Alexis Harte, UFORE project coordinator; Leslie Bandy, survey coordination; Karin Avila, Sarah Cobey, Maria D'agostino, Rachel Freund, Meleana Judd, Lorraine Maldague, Jennifer Mar, and Kelly Palomera, surveyors.

Published by:
USDA FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073-3294

February 2007

For additional copies:
USDA Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740)368-0152

Visit our homepage at: **http://www.nrs.fs.fed.us**

Urban forests provide numerous benefits to society, yet relatively little is known about this important resource.

In 2004, the UFORE model was used to survey and analyze San Francisco's urban forest.

The calculated environmental benefits of the urban forest are significant, yet many environmental and social benefits still remain to be quantified.

Executive Summary

Trees in cities can contribute significantly to human health and environmental quality. Unfortunately, little is known about the urban forest resource and what it contributes to the local and regional society and economy. To better understand the urban forest resource and its numerous values, the USDA Forest Service, Northern Research Station, developed the Urban Forest Effects (UFORE) model. Results from this model are used to advance the understanding of the urban forest resource, improve urban forest policies, planning and management, provide data for potential inclusion of trees within environmental regulations, and determine how trees affect the environment and consequently enhance human health and environmental quality in urban areas.

Forest structure is a measure of various physical attributes of the vegetation, such as tree species composition, number of trees, tree density, tree health, leaf area, biomass, and species diversity. Forest functions, which are determined by forest structure, include a wide range of environmental and ecosystem services such as air pollution removal and cooler air temperatures. Forest values are an estimate of the economic worth of the various forest functions.

To help determine the vegetation structure, functions, and values of the urban forest in San Francisco, a vegetation assessment was conducted during the summer of 2004. For this assessment, one-tenth acre field plots were sampled and analyzed using the UFORE model. This report summarizes results and values of:

- Forest structure
- Potential risk to forest from insects or diseases
- Air pollution removal
- Carbon storage
- Annual carbon removal (sequestration)

San Francisco Urban Forest Summary

Feature	Measure
Number of trees	669,000
Tree cover	11.9%
Most common species	blue gum eucalyptus, Monterey pine, Monterey cypress
Percentage of trees < 6-inches diameter	51.5%
Pollution removal	260 tons/year ($1.3 million/year)
Carbon storage	196,000 tons ($3.6 million)
Carbon sequestration	5,200 tons/year ($95,000/year)
Structural value	$1.7 billion
Ton – short ton (U.S.) (2,000 lbs)	

Benefits ascribed to urban trees include:

- Air pollution removal
- Air temperature reduction
- Reduced building energy use
- Absorption of ultraviolet radiation
- Improved water quality
- Reduced noise
- Improved human comfort
- Increased property value
- Improved physiological & psychological well-being
- Aesthetics
- Community cohesion

Urban Forest Effects Model and Field Measurements

Though urban forests have many functions and values, currently only a few of these attributes can be assessed. To help assess the city's urban forest, data from 194 field plots located throughout the city were analyzed using the Forest Service's Urban Forest Effects (UFORE) model.[1]

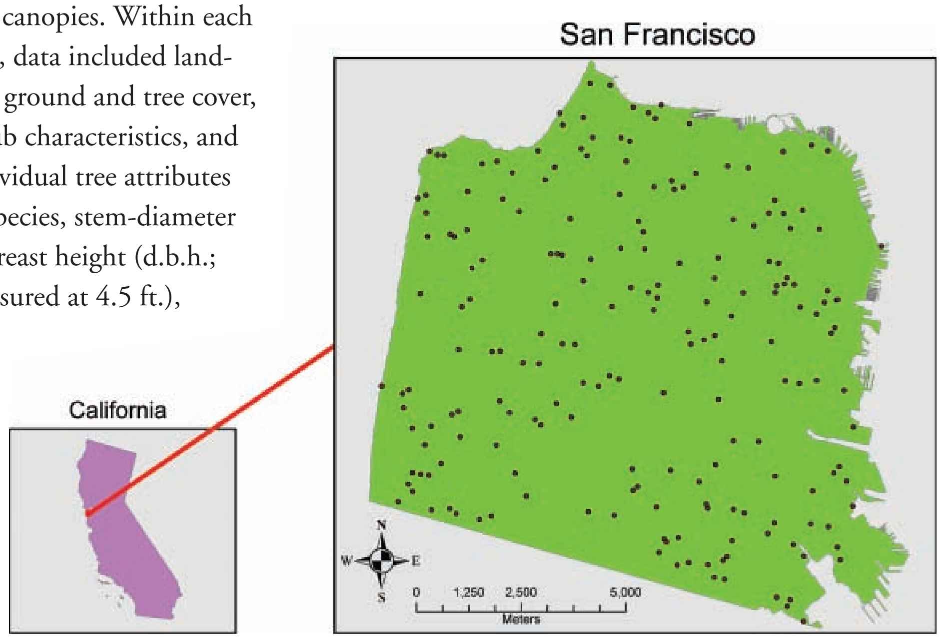
UFORE is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects, including:

- Urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass, species diversity, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<10 microns).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Potential impact of infestations by Asian longhorned beetles, emerald ash borers, gypsy moth, and Dutch elm disease.

For more information go to http://www.ufore.org

In the field, one-tenth acre plots were randomly located in the different land use strata of San Francisco. These land uses were used to divide the analysis into smaller zones. The plots were divided among the following land uses: commercial/industrial (20 plots), institutional (10 plots), street/right-of-way (30 plots), open space (65 plots), residential (58 plots), vacant (11 plots). This distribution allows for comparison among land uses.

Field data were collected for the Forest Service by San Francisco Department of the Environment; data collection took place during the leaf-on season to properly assess tree canopies. Within each plot, data included land-use, ground and tree cover, shrub characteristics, and individual tree attributes of species, stem-diameter at breast height (d.b.h.; measured at 4.5 ft.),



tree height, height to base of live crown, crown width, and percentage crown canopy missing and dieback.[2]

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations.[3] To adjust for this difference, biomass results for open-grown urban trees are multiplied by 0.8.[3] No adjustment is made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Field Survey Data

Plot Information

- Land use type
- Percent tree cover
- Percent shrub cover
- Percent plantable
- Percent ground cover types
- Shrub species/ dimensions

Tree parameters

- Species
- Stem diameter
- Total height
- Height to crown base
- Crown width
- Percent foliage missing
- Percent dieback
- Crown light exposure

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models.[4, 5] As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[6, 7] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere.[8]

Compensatory values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information.[9]

To learn more about UFORE methods[10] visit: http://www.nrs.fs.fed.us/UFORE/data/ or www.ufore.org

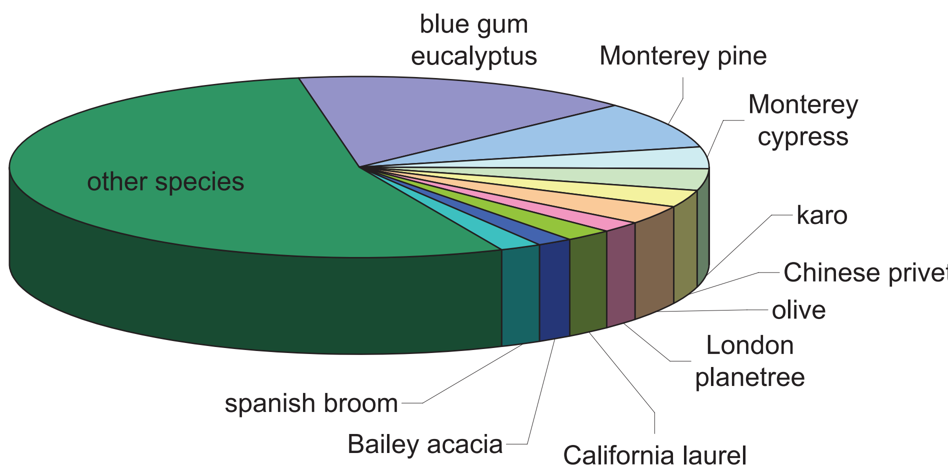
There are an estimated 669,000 trees in San Francisco with canopies that cover 11.9 percent of the city.

The 10 most common species account for 46.2 percent of the total number of trees.

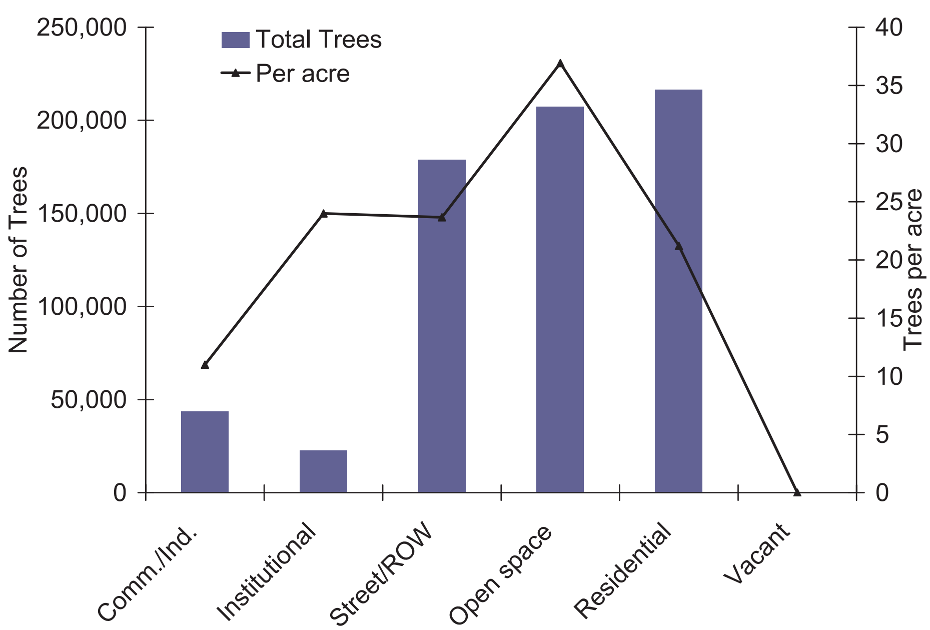
Tree density is highest in open space, and lowest in the vacant land use.

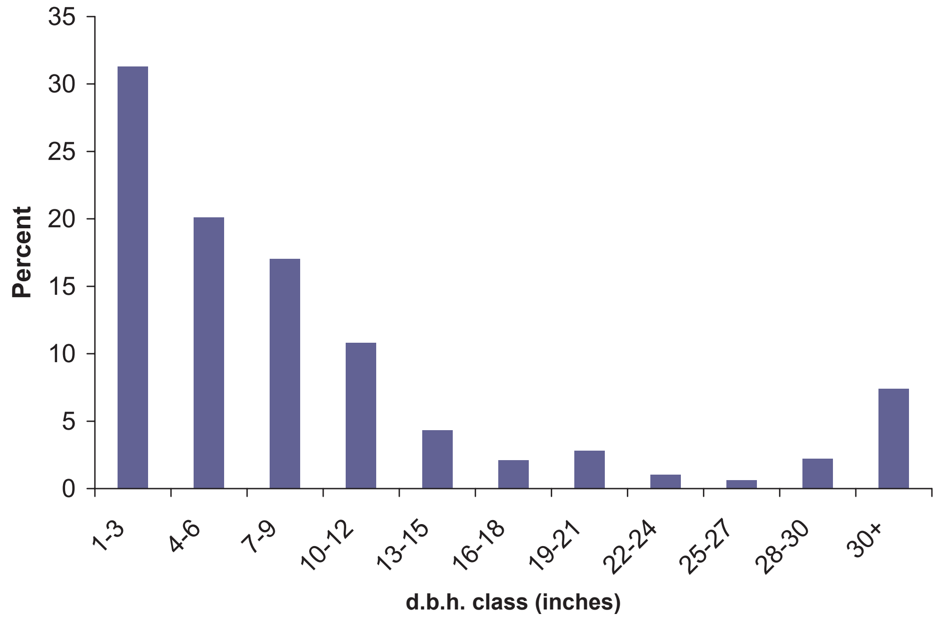
Tree Characteristics of the Urban Forest

The urban forest of San Francisco has an estimated 669,000 trees with a tree cover of 11.9 percent. Trees that have diameters less than 6 inches account for 51.4 percent of the population. The three most common species in the urban forest are blue gum eucalyptus (15.9 percent), Monterey pine (8.4 percent), and Monterey cypress (3.8 percent). The 10 most common species account for 46.2 percent of all trees; their relative abundance is illustrated below.



The highest density of trees occurs in the open space (36.9 trees/acre), followed by the institutional land (24.0 trees/acre) and street right of ways (23.7 trees/acre). The overall tree density in San Francisco is 22.5 trees/acre, which is comparable to other city tree densities (Appendix I), of 14.4 to 119.2 trees/acre.

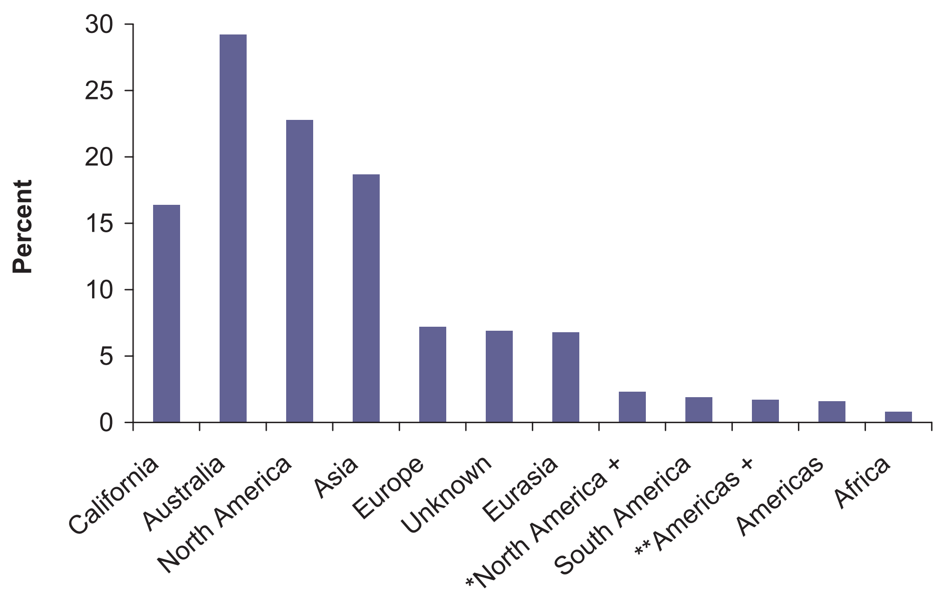




Sixteen percent of the tree species in San Francisco are native to California.

Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means.

Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. An increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but the increase in the number of exotic plants can also pose a risk to native plants if some of the exotics species are invasive plants that can potentially out-compete and displace native species. In San Francisco, about 16 percent of the trees are from species native to California. Trees with a native origin outside of North America are mostly from Australia (29.3 percent of the species).



*North America + refers to tree species that are native to North America and one other continent.

**Americas + refers to tree species that are native to North and South America and one other continent.

Healthy leaf area equates directly to tree benefits provided to the community.

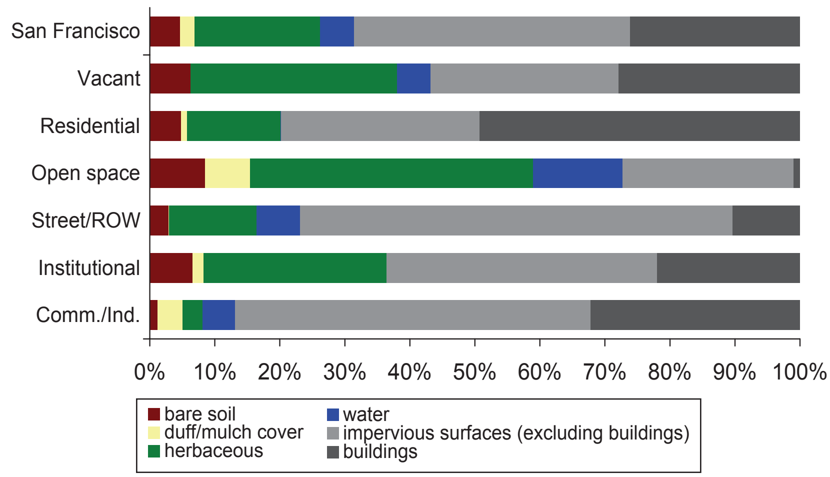
Monterey pine has the greatest importance to the San Francisco urban forest based on relative leaf area and relative population.

Common Name	% Pop[a]	% LA[b]	IV[c]
Monterey pine	8.4	22.2	30.6
blue gum eucalyptus	15.9	10.7	26.6
Monterey cypress	3.8	14.2	18.0
karo	3.8	3.0	6.8
Chinese privet	3.2	3.4	6.6
olive	3.1	2.2	5.3
London planetree	2.1	2.8	4.9
Bailey acacia	1.9	2.4	4.3
black acacia	1.8	2.4	4.2
Califonia laurel	2.1	1.7	3.8

[a] percent of population
[b] percent of leaf area
[c] percent Pop + percent LA

Urban Forest Cover and Leaf Area

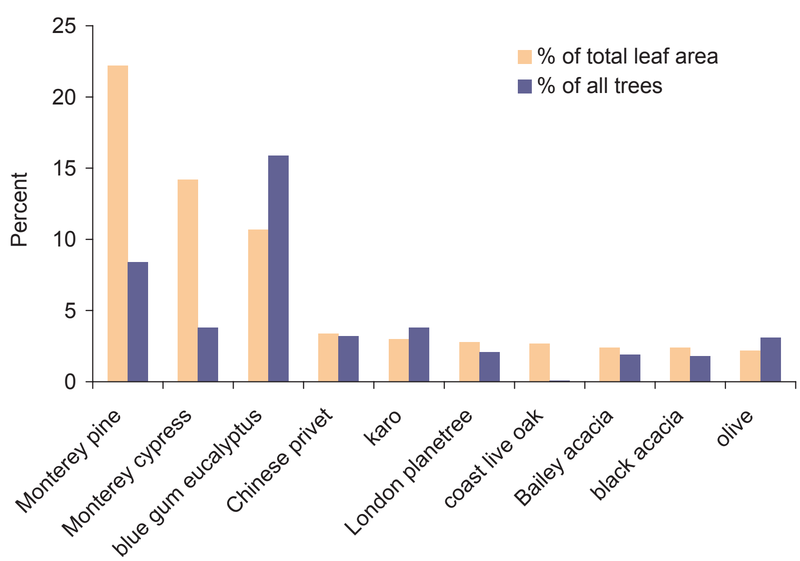
Trees cover about 11.9 percent of San Francisco; shrubs cover 6.9 percent of the city. Dominant ground cover types include impervious surfaces (excluding buildings) (e.g., driveways, sidewalks, parking lots) (42.5 percent), buildings (26.1 percent), and herbaceous (e.g., grass, gardens) (19.3 percent).



Many tree benefits are linked directly to the amount of healthy leaf surface area of the plant. In San Francisco trees that dominate in terms of leaf area are Monterey pine, Monterey cypress, and blue gum eucalyptus.

Tree species with relatively large individuals contributing leaf area to the population (species with percent of leaf area much greater than percent of total population) are Monterey cypress and Monterey pine. Smaller trees in the population are Indian laurel fig and apple (species with percent of leaf area much less than percent of total population). A species must also constitute at least 1 percent of the total population to be considered as relatively large or small trees in the population.

The importance values (IV) are calculated using a formula that takes into account the relative leaf area and relative abundance. The most important species in the urban forest, according to calculated IVs, are Monterey pine, blue gum eucalyptus, and Monterey cypress.



Air Pollution Removal by Urban Trees

The urban forest of San Francisco removes approximately 260 tons of pollutants each year, with a societal value of $1.3 million/year.

General urban forest management recommendations to improve air quality are given in Appendix II.

Poor air quality is a common problem in many urban areas. It can lead to human health problems, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduce air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation.[11]

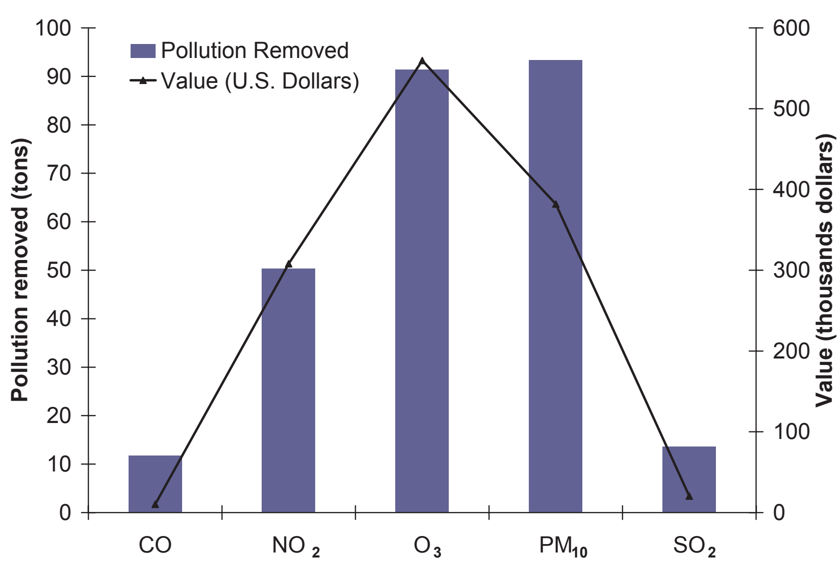
Pollution removal by trees and shrubs in San Francisco was estimated using the UFORE model in conjunction with field data and hourly pollution and weather data for the year 2000. Pollution removal was greatest for particulate matter less than 10 microns (PM_{10}), followed by ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). It is estimated that trees and shrubs remove 260 tons of air pollution (CO, NO_2, O_3, PM_{10}, SO_2) per year with an associated value of $1.3 million (based on estimated national median externality costs associated with pollutants[12]). Trees remove about 19 percent more air pollution than shrubs in San Francisco.

The average percentage of air pollution removal during the daytime, in-leaf season was estimated to be:

- O_3 0.41%
- SO_2 0.40%
- CO 0.002%
- PM_{10} 0.34%
- NO_2 0.24%

Peak 1-hour air quality improvements during the in-leaf season for heavily-treed areas were estimated to be:

- O_3 11.9%
- SO_2 12.3%
- CO 0.05%
- PM_{10} 9.3%
- NO_2 5.7%



Carbon storage:

Carbon currently held in tree tissue (roots, stems, and branches).

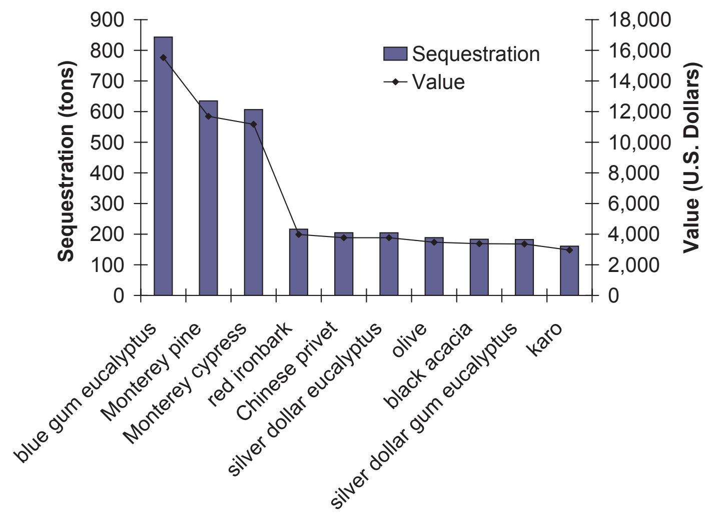
Carbon sequestration:

Estimated amount of carbon removed annually by trees. Net carbon sequestration can be negative if emission of carbon from decomposition is greater than amount sequestered by healthy trees.

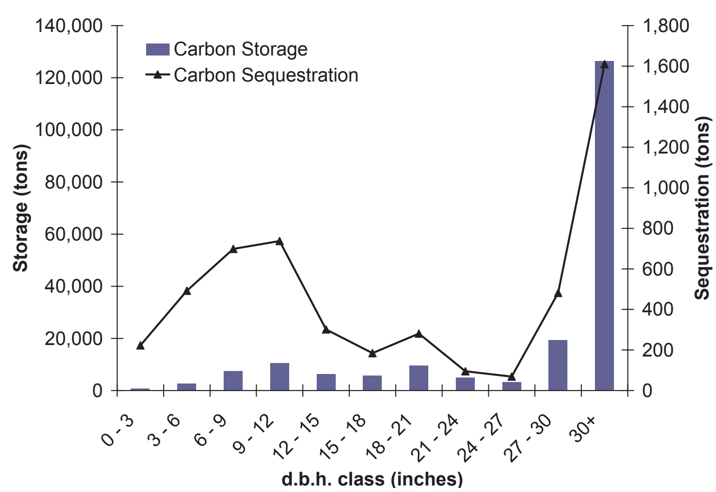
Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel based power plants.[13]

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new tissue growth every year. The amount of carbon annually sequestered is increased with healthier trees and larger diameter trees. Gross sequestration by trees in San Francisco is about 5,200 tons of carbon per year with an associated value of $95,000. Net carbon sequestration in the San Francisco urban forest is about 4,700 tons.



Carbon storage by trees is another way trees can influence global climate change. As trees grow, they store more carbon by holding it in their accumulated tissue. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in San Francisco are estimated to store 196,000 tons of carbon ($3.6 million). Of all the species sampled, blue gum eucalyptus stores and sequesters the most carbon (approximately 24.4% of the total carbon stored and 16.3% of all sequestered carbon).



Urban forests have a structural value based on the tree itself.

Urban forests also have functional values based on the functions the tree performs.

Large, healthy, long-lived trees provide the greatest structural and functional values.

A map of priority planting locations for San Francisco is given in Appendix IV.

Structural and Functional Values

Urban forests have a structural value based on the tree itself (e.g., the cost of having to replace the tree with a similar tree). The structural value[9] of the urban forest in San Francisco is about $1.7 billion. The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees.

Urban forests also have functional values (either positive or negative) based on the functions the tree performs. Annual functional values also tend to increase with increased number and size of healthy trees, and are usually on the order of several million dollars per year. There are many other functional values of the urban forest, though they are not quantified here (e.g., reduction in air temperatures and ultra-violet radiation, improvements in water quality). Through proper management, urban forest values can be increased. However, the values and benefits also can decrease as the amount of healthy tree cover declines.

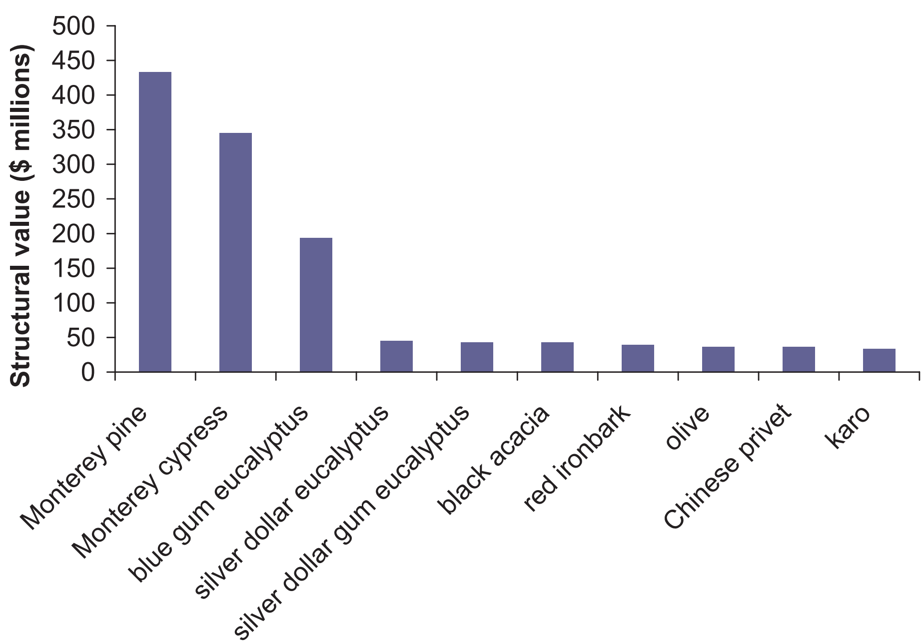
Structural values:

- Structural value: $1.7 billion
- Carbon storage: $3.6 million

Annual functional values:

- Carbon sequestration: $95,000
- Pollution removal: $3.9 million

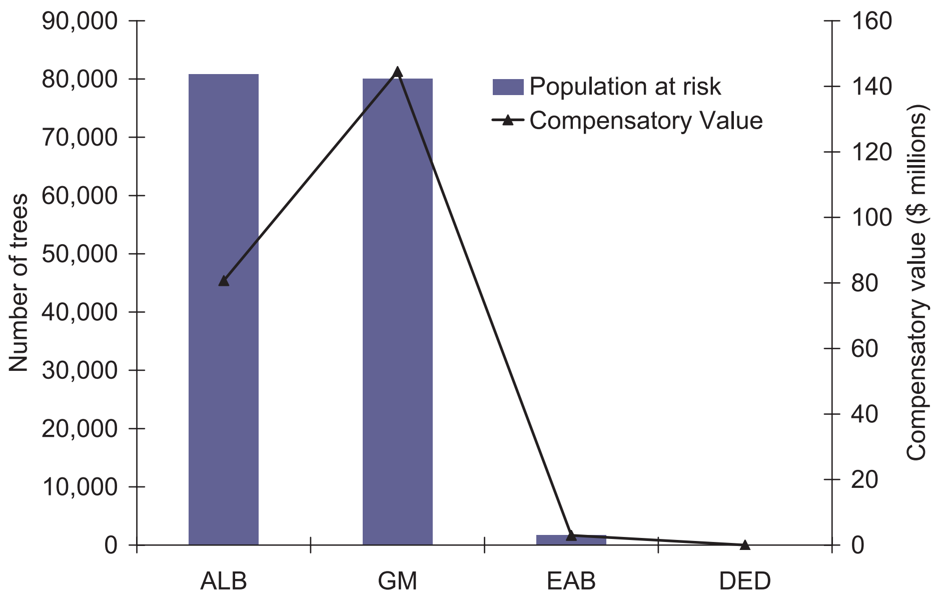
More detailed information on the urban forest in San Francisco can be found at http://www.nrs.fs.fed.us/UFORE/data. Additionally, information on other urban forest values can be found in Appendix I and information comparing tree benefits to estimates of average carbon emissions in the city, average automobile emissions, and average household emissions can be found in Appendix III.



Potential Insect and Disease Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As various pests have differing tree hosts, the potential damage or risk of each pest will differ. Four exotic pests were analyzed for their potential impact: Asian longhorned beetle, gypsy moth, emerald ash borer, and Dutch elm disease.

The Asian longhorned beetle (ALB)[14] is an insect that bores into and kills a wide range of hardwood species. ALB represents a potential loss to the San Francisco urban forest of $81 million in structural value (12.1 percent of the tree population).

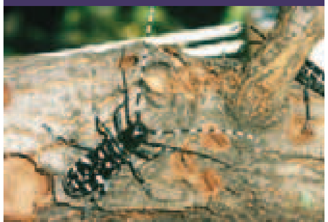


The gypsy moth (GM)[15] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest could potentially result in damage to or a loss of $144 million in structural value (12.0 percent of the population).

Emerald ash borer (EAB)[16] has killed thousands of ash trees in Michigan, Ohio, and Indiana. EAB has the potential to affect 0.3 percent of the population ($2.9 million in structural value).

American elm, one of the most important street trees in the 20th century, has been devastated by the Dutch elm disease (DED). Since first reported in the 1930s, it has killed more than 50 percent of the native elm population in the United States.[17] The analysis of San Francisco shows that Dutch elm disease would have a limited effect on the urban forest as no elm trees were tallied in the sample. However, the lack of elms in the sample does not mean that no elms exist with San Francisco's urban forest.

Asian longhorned beetle



Kenneth R. Law
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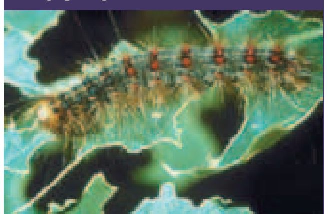
(www.invasive.org)

Gypsy moth

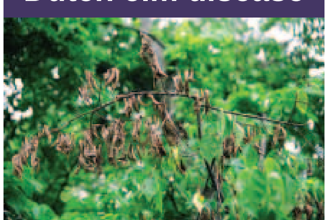


USDA Forest Service Archives
(www.invasive.org)

Emerald ash borer

David Cappaert
Michigan State University
(www.invasive.org)

Dutch elm disease



Appendix I. Comparison of Urban Forests

A commonly asked question is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the UFORE model.

I. City totals, trees only

City	% Tree cover	Number of trees	Carbon storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (tons/yr)	Pollution value U.S. $
Calgary, Canada[a]	7.2	11,889,000	445,000	21,400	326	1,611,000
Atlanta, GA[b]	36.7	9,415,000	1,344,000	46,400	1,663	8,321,000
Toronto, Canada[c]	20.5	7,542,000	992,000	40,300	1,212	6,105,000
New York, NY[b]	20.9	5,212,000	1,350,000	42,300	1,677	8,071,000
Baltimore, MD[d]	21.0	2,627,000	597,000	16,200	430	2,129,000
Philadelphia, PA[b]	15.7	2,113,000	530,000	16,100	576	2,826,000
Washington, DC[e]	28.6	1,928,000	526,000	16,200	418	1,956,000
Boston, MA[b]	22.3	1,183,000	319,000	10,500	284	1,426,000
Woodbridge, NJ[f]	29.5	986,000	160,000	5,560	210	1,037,000
Minneapolis, MN[g]	26.4	979,000	250,000	8,900	306	1,527,000
Syracuse, NY[d]	23.1	876,000	173,000	5,420	109	568,000
San Francisco, CA[a]	11.9	668,000	194,000	5,100	141	693,000
Morgantown, WV[h]	35.5	658,000	93,000	2,890	72	333,000
Moorestown, NJ[f]	28.0	583,000	117,000	3,760	118	576,000
Jersey City, NJ[f]	11.5	136,000	21,000	890	41	196,000
Freehold, NJ[f]	34.4	48,000	20,000	545	22	110,000

II. Per acre values of tree effects

City	No. of trees	Carbon Storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (lbs/yr)	Pollution value U.S. $
Calgary, Canada[a]	66.7	2.5	0.12	3.7	9.0
Atlanta, GA[b]	111.6	15.9	0.55	39.4	98.6
Toronto, Canada[c]	48.3	6.4	0.26	15.5	39.1
New York, NY[b]	26.4	6.8	0.21	17.0	40.9
Baltimore, MD[d]	50.8	11.6	0.31	16.6	41.2
Philadelphia, PA[b]	25.1	6.3	0.19	13.6	33.5
Washington, DC[e]	49.0	13.4	0.41	21.3	49.7
Boston, MA[b]	33.5	9.1	0.30	16.1	40.4
Woodbridge, NJ[f]	66.5	10.8	0.38	28.4	70.0
Minneapolis, MN[g]	26.2	6.7	0.24	16.4	40.9
Syracuse, NY[d]	54.5	10.8	0.34	13.5	35.4
San Francisco, CA[a]	22.5	6.6	0.17	9.5	23.4
Morgantown, WV[h]	119.2	16.8	0.52	26.0	60.3
Moorestown, NJ[f]	62.1	12.4	0.40	25.1	61.3
Jersey City, NJ[f]	14.4	2.2	0.09	8.6	20.7
Freehold, NJ[f]	38.3	16.0	0.44	34.9	88.2

Data collection group

[a] City personnel
[b] ACRT, Inc.
[c] University of Toronto
[d] U.S. Forest Service
[e] Casey Trees Endowment Fund
[f] New Jersey Department of Environmental Protection
[g] Davey Resource Group
[h] West Virginia University

Appendix II. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmospheric environment. Four main ways that urban trees affect air quality are:

Temperature reduction and other microclimatic effects
Removal of air pollutants
Emission of volatile organic compounds (VOC) and tree maintenance emissions
Energy conservation in buildings and consequent power plant emissions

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the overall impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities. Local urban forest management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include:

Strategy	Reason
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree cover	Maintain pollution removal levels
Maximize use of low VOC-emitting trees	Reduces ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduce long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample water to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improve tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles

Appendix III. Relative Tree Effects

The urban forest in San Francisco provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate a relative value of these benefits, tree benefits were compared to estimates of average carbon emissions in the city[18], average passenger automobile emissions[19], and average household emissions.[20]

General tree information:

Average tree diameter (d.b.h.) = 9.4 in.
Median tree diameter (d.b.h.) = 5.7 in.
Average number of trees per person = 0.9
Number of trees sampled = 478
Number of species sampled = 103

Average tree effects by tree diameter:

D.b.h.	Carbon storage			Carbon sequestration			Pollution removal	
Class (inch)	(lbs)	($)	(miles) [a]	(lbs/yr)	($/yr)	(miles) [a]	(lbs)	($)
1-3	8	0.08	30	1.9	0.02	7	0.1	0.18
3-6	57	0.53	210	6.7	0.06	24	0.2	0.45
6-9	172	1.59	630	10.8	0.10	40	0.4	0.98
9-12	342	3.15	1,250	17.1	0.16	63	0.6	1.57
12-15	587	5.40	2,150	21.6	0.20	79	0.8	2.04
15-18	973	8.96	3,560	29.7	0.27	109	1.3	3.24
18-21	1,443	13.29	5,290	37.0	0.34	135	1.8	4.50
21-24	1,930	17.77	7,070	50.3	0.46	184	1.7	4.17
24-27	2,606	24.00	9,540	67.5	0.62	247	2.3	5.58
27-30	3,463	31.90	12,680	82.7	0.76	303	2.8	6.93
30+	6,152	56.66	22,530	92.0	0.85	337	3.0	7.36

[a] miles = number of automobile miles driven that produces emissions equivalent to tree effect

The San Francisco urban forest provides:

Carbon storage equivalent to:
Amount of carbon (C) emitted in city in 16 days or
Annual carbon emissions from 118,000 automobiles or
Annual C emissions from 59,200 single family houses

Carbon monoxide removal equivalent to:
Annual carbon monoxide emissions from 30 automobiles or
Annual carbon monoxide emissions from 100 single family houses

Nitrogen dioxide removal equivalent to:
Annual nitrogen dioxide emissions from 1,700 automobiles or
Annual nitrogen dioxide emissions from 1,100 single family houses

Sulfur dioxide removal equivalent to:
Annual sulfur dioxide emissions from 11,600 automobiles or
Annual sulfur dioxide emissions from 200 single family houses

Particulate matter less than 10 micron (PM_{10}) removal equivalent to:
Annual PM_{10} emissions from 124,400 automobiles or
Annual PM_{10} emissions from 12,000 single family houses

Annual C sequestration equivalent to:
Amount of C emitted in city in 0.4 days or
Annual C emissions from 3,100 automobiles or
Annual C emissions from 1,600 single family homes

Appendix IV. Tree Planting Index Map

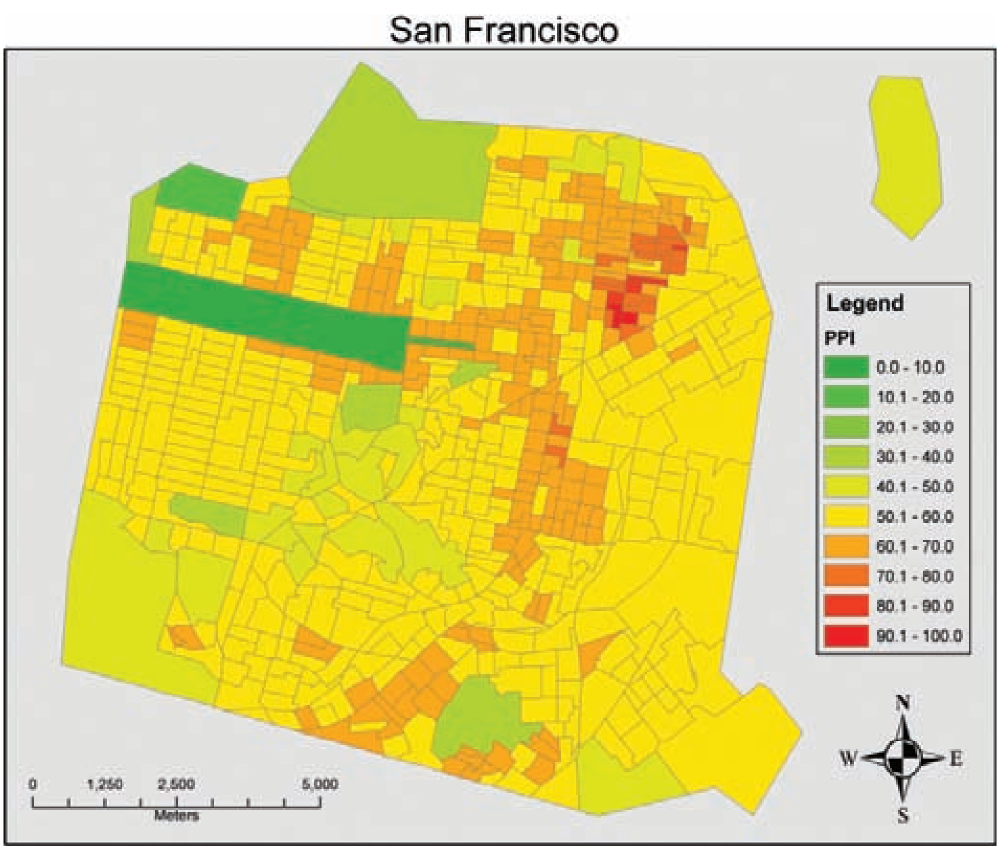
To determine the best locations to plant trees, tree canopy and impervious cover maps from National Land Cover Data[21] were used in conjunction with 2000 U.S. Census data to produce an index of priority planting areas. Index values were produced for each census block with the higher the index value, the higher the priority of the area for tree planting. This index is a type of "environmental equity" index with areas with higher human population density and lower tree cover tending to get the higher index value. The criteria used to make the index were:

- Population density: the greater the population density, the greater the priority for tree planting
- Tree stocking levels: the lower the tree stocking level (the percent of available greenspace (tree, grass, and soil cover areas) that is occupied by tree canopies), the greater the priority for tree planting
- Tree cover per capita: the lower the amount of tree canopy cover per capita (m^2/capita), the greater the priority for tree planting

Each criteria was standardized[22] on a scale of 0 to 1 with 1 representing the census block with the highest value in relation to priority of tree planting (i.e., the census block with highest population density, lowest stocking density or lowest tree cover per capita were standardized to a rating of 1). Individual scores were combined and standardized based on the following formula to produce an overall priority index value between 0 and 100:

$$I = (PD * 40) + (TS * 30) + (TPC * 30)$$

Where I = index value, PD is standardized population density, TS is standardized tree stocking, and TPC is standardized tree cover per capita.



Appendix V. List of Species Sampled in San Francisco

			%	%		Potential pest [b]			
Genus	Species	Common Name	Population	Leaf Area	IV[a]	ALB	GM	EAB	DED
Abies	grandis	grand fir	0.3	0.1	0.4				
Acacia	baileyana	Bailey acacia	1.9	2.4	4.3				
Acacia	dealbata	silver wattle	0.3	0.1	0.4				
Acacia	longifolia	Sydney golden wattle	0.1	0.2	0.3				
Acacia	melanoxylon	black acacia	1.8	2.4	4.2				
Acacia	species	acacia	0.4	0.2	0.6				
Acer	palmatum	Japanese maple	1.1	0.3	1.4	▲			
Arbutus	unedo	strawberry tree	0.6	0.3	0.9				
Betula	papyrifera	paper birch	0.5	0.3	0.8	▲	▲		
Buxus	sempervirens	common boxwood	0.3	0.0	0.3				
Callistemon	pendula	bottlebrush	0.5	0.1	0.6				
Camellia	species	camellia	1.0	0.2	1.2				
Ceratonia	siliqua	Judas tree	0.3	0.3	0.6				
Citrus	aurantifolia	lime	0.3	0.0	0.3				
Citrus	limon	lemon	0.8	0.1	0.9				
Cordyline	australis	cordyline	0.4	0.2	0.6				
Cornus	racemosa	gray dogwood	1.1	1.8	2.9				
Cotoneaster	species	cotoneaster	0.8	0.1	0.9				
Crataegus	oxyacantha	English hawthorn	0.3	0.1	0.4				
Crataegus	phaenopyrum	Washington hawthorn	0.4	0.0	0.4				
Cupaniopsis	anacardioides	carrotwood	0.8	0.1	0.9				
Cupressus	macrocarpa	Monterey cypress	3.8	14.2	18.0				
Cyathea	arborea	tree-fern	1.2	0.2	1.4				
Dodonaea	viscosa	hop bush	0.5	0.1	0.6				
Dracaena	spp.	dracaena	0.3	0.0	0.3				
Eucalyptus	cinerea	silver dollar eucalyptus	1.3	1.8	3.1		▲		
Eucalyptus	ficifolia	red-flowering gum	0.4	0.2	0.6				

Continued

Appendix V continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest[b] ALB	GM	EAB	DED
Eucalyptus	globulus	blue gum eucalyptus	15.9	10.7	26.6				
Eucalyptus	polyanthemos	silver dollar gum eucalyptus	0.8	0.7	1.5				
Eucalyptus	sideroxylon	red ironbark	1.3	0.4	1.7				
Eucalyptus	species	eucalyptus	0.1	0.3	0.4				
Ficus	carica	common fig	1.0	0.6	1.6				
Ficus	macrocarpa	Moreton Bay fig	0.4	0.3	0.7				
Ficus	microcarpa	Indian laurel fig	1.7	0.2	1.9				
Fraxinus	oxycarpa	caucasian ash	0.3	0.1	0.4	▲		▲	
Fuchsia	species	fuchsia	0.3	0.0	0.3				
Geijera	parviflora	Australian willow	0.4	0.1	0.5				
Ginkgo	biloba	ginkgo	0.4	0.0	0.4				
Gleditsia	triacanthos	honeylocust	0.3	0.0	0.3				
Heteromeles	arbutifolia	Christmasberry	0.1	0.0	0.1				
Ilex	aquifolium	English holly	0.3	0.5	0.8				
Ilex	species	holly	0.3	0.1	0.4				
Jacaranda	mimosifolia	jacaranda	0.6	1.4	2.0				
Juniperus	species	juniper	1.2	0.2	1.4				
Juniperus	torulosu	Hollywood juniper	0.3	0.0	0.3				
Larix	leptolepis	Japanese larch	0.1	0.7	0.8				
Laurus	nobilis	sweet bay	0.5	1.4	1.9				
Lavatera	assurgentiflora	mallow	0.3	0.1	0.4				
Leptospermum	laevigatum	Australian tea tree	0.1	0.1	0.2				
Ligustrum	lucidum	Chinese privet	3.2	3.4	6.6				
Ligustrum	species	privet	1.6	0.3	1.9				
Magnolia	grandiflora	southern magnolia	1.1	0.3	1.4				
Magnolia	species	magnolia	0.1	0.5	0.6				
Magnolia	x soulangeana	saucer magnolia	0.1	0.6	0.7				

Continued

Appendix V continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest [b]			
						ALB	GM	EAB	DED
Malus	species	crabapple	0.3	0.1	0.4	🌲	🌲		
Malus	sylvestris	apple	1.6	0.2	1.8	🌲	🌲		
Manikara	bahamensis	wild dilly	0.4	0.1	0.5				
Maytenus	boaria	mayten	0.9	0.3	1.2				
Melaleuca	quinquenervia	cajeput tree	0.7	0.1	0.8				
Michelia	doltsopa	michelia	0.3	0.2	0.5				
Myoporum	laetum	myoporum	1.6	1.0	2.6				
Olea	europaea	olive	3.1	2.2	5.3				
Other	species	other species	0.8	1.9	2.7				
Palm	species	palm	0.3	0.0	0.3				
Persea	americana	avocado	0.7	0.7	1.4				
Photinia	xfraseri	Fraser photinia	0.3	0.0	0.3				
Pinus	pinea	Italian stone pine	0.3	0.3	0.6				
Pinus	radiata	Monterey pine	8.4	22.2	30.6				
Pinus	resinosa	red pine	0.3	0.1	0.4				
Pinus	species	pine	0.3	1.4	1.7				
Pittosporum	crassifolium	karo	3.8	3.0	6.8				
Pittosporum	eugenioides	tarata	0.5	0.1	0.6				
Pittosporum	tobira	Japanese pittosporum	0.3	0.2	0.5				
Pittosporum	undulatum	victorian box	1.9	0.8	2.7				
Platanus	acerifolia	London planetree	2.1	2.8	4.9	🌲			
Podocarpus	gracilior	fern pine	0.5	0.1	0.6				
Prunus	armeniaca	apricot	0.3	0.1	0.4	🌲	🌲		
Prunus	cerasifera	cherry plum	1.1	1.7	2.8	🌲			
Prunus	cerasifera var. niga	purpleleaf flowering plum	0.3	0.0	0.3				
Prunus	domestica	common plum	0.7	0.4	1.1	🌲			
Prunus	laurocerasus	common cherry laurel	0.8	0.2	1.0	🌲			

Continued

Appendix V continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest[b] ALB	GM	EAB	DED
Prunus	lusitanica	Portugal laurel	0.5	1.7	2.2				
Prunus	persica	nectarine	0.5	0.0	0.5	▲			
Prunus	serrulata	Kwanzan cherry	0.8	0.2	1.0	▲			
Prunus	species	cherry	0.5	0.2	0.7	▲			
Pyracantha	species	firethorn	0.3	0.3	0.6				
Pyrus	kawakamii	evergreen pear	0.9	0.3	1.2	▲			
Quercus	agrifolia	coast live oak	0.1	2.7	2.8		▲		
Quercus	species	oak	0.5	0.2	0.7		▲		
Raphiolepis	indica	Indian hawthorn	0.8	0.1	0.9				
Rhus	species	sumac	0.4	0.3	0.7				
Sabal	palmetto	cabbage palmetto	0.9	0.4	1.3				
Spartium	junceum	Spanish broom	1.9	0.3	2.2				
Taxus	baccata	English yew	0.8	0.1	0.9				
Taxus	species	yew	0.3	0.1	0.4				
Terminalia	catappa	Almendra	0.1	0.4	0.5				
Terminalina	catappa	almond	0.1	0.4	0.5	▲			
Trachycarpus	fortunei	windmill palm	0.4	0.1	0.5				
Tristania	conferta	Brisbane box	1.1	1.6	2.7				
Umbellularia	californica	California laurel	2.1	1.7	3.8				
Washingtonia	filifera	California palm	0.6	0.0	0.6				
Washingtonia	robusta	Mexican fan palm	0.3	0.1	0.4				
Yucca	aloifolia	aloe yucca	0.4	0.2	0.6				

[a] IV = importance value (% population + % leaf area)

[b] ALB = Asian longhorned bettel; GM = gypsy moth; EAB = emerald ash borer; DED = Dutch elm disease

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Explanation of Calculations of Appendix III and IV

18 Total city carbon emissions were based on 2003 U.S. per capita carbon emissions, calculated as total U.S. carbon emissions (Energy Information Administration, 2003, Emissions of Greenhouse Gases in the United States 2003. http://www.eia.doe.gov/oiaf/1605/1605aold.html) divided by 2003 total U.S. population (www.census.gov). Per capita emissions were multiplied by Minneapolis population to estimate total city carbon emissions.

19 Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Carbon dioxide emissions from automobiles assumed 6 pounds of carbon per gallon of gasoline with energy costs of refinement and transportation included (Graham, R.L.; Wright, L.L.; Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO_2 emissions. Climatic Change. 22:223-238.)

20 Average household emissions based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household from:

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CO_2, SO_2, and NOx power plant emission per KWh from:

U.S. Environmental Protection Agency. U.S. power plant emissions total by year www.epa.gov/cleanenergy/egrid/samples.htm.

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http://www.energy.ca.gov/2005_energypolicy/documents/2004-11-15_workshop/2004-11-15_03-A_LAYTON.PDF

CO_2, NOx, SO_2, PM_{10}, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from:

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Emissions per dry tonne of wood converted to emissions per Btu based on average dry weight per cord of wood and average Btu per cord from:

Kuhns, M.; Schmidt, T. 1988. Heating with wood: species characteristics and volumes I. NebGuide G-88-881-A. Lincoln, NE: University of Nebraska, Institute of Agriculture and Natural Resources, Cooperative Extension.

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22 Standardized value for population density was calculated as:

$$PD = (n - m)/r$$

where:

PD is the value (0-1)
n is the value for the census block (population/km^2)
m is the minimum value for all census blocks, and
r is the range of values among all census blocks (maximum value – minimum value).

Standardized value for tree stocking was calculated as :

$$TS = (1 - (T/(T+G))$$

where:

TS is the value (0-1)
T is percent tree cover, and
G is percent grass cover.

Standardized value for tree cover per capita was calculated as:

$$TPC = 1 - [(n - m)/r]$$

where:

TPC is the value (0-1)
n is the value for the census block (m^2/capita)
m is the minimum value for all census blocks, and
r is the range of values among all census blocks (maximum value – minimum value).

Nowak, David J.; Hoehn, Robert E. III, Crane, Daniel E.; Stevens, Jack C.; Walton, Jeffrey T. 2007. **Assessing urban forest effects and values, San Francisco's urban forest.** Resour. Bull. NRS-8. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 22 p.

An analysis of trees in San Francisco, CA reveals that this city has about 669,000 trees with canopies that cover 11.9 percent of the area. The most common tree species are blue gum eucalyptus, Monterey pine, and Monterey cypress. The urban forest currently stores about 196,000 tons of carbon valued at $3.6 million. In addition, these trees remove about 5,200 tons of carbon per year ($95,000 per year) and about 260 tons of air pollution per year ($1.3 million per year). The structural, or compensatory, value is estimated at $1.7 billion. Information on the structure and functions of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the San Francisco area.

KEY WORDS**:** urban forestry, ecosystem services, air pollution removal, carbon sequestration, tree value

Printed on Recycled Paper

Manuscript received for publication 18 December 2006

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