City of Honolulu, Hawai'i
Municipal Forest Resource Analysis

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Center for Urban Forest Research
USDA Forest Service, Pacific Southwest Research Station

Technical Report to:
Stan Oka, Urban Forestry Administrator
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City and County of Honolulu

—November 2007—

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Table of Contents

Executive Summary

Honolulu is one of America's favorite cities, and trees play a special role in creating the beautiful environment that so many people want to visit and call home. The trees of Honolulu are a living representation of the majesty and history of Hawaiʻi, and the city's Division of Urban Forestry cares for them as an integral component of the urban infrastructure (*Figure 1*).

Trees are a critical component of cities. Research indicates that healthy trees can lessen impacts associated with the built environment by reducing stormwater runoff, energy consumption, and air pollutants. Trees improve urban life, making Honolulu a more enjoyable place to live, work, and play, while mitigating the city's environmental impact. Over the years, the people of Honolulu have invested millions of dollars in their municipal forest. The primary question that this study asks is whether the accrued benefits from Honolulu's municipal forest justify the annual expenditures.

This analysis combines results of a partial citywide inventory with benefit-cost modeling data to produce four types of information on the city-managed street tree resource:

- Structure (species composition, diversity, age distribution, condition, etc.)
- Function (magnitude of annual environmental and aesthetic benefits)
- Value (dollar value of benefits minus management costs)
- Management needs (sustainability, planting, maintenance)

Resource Structure

The Division of Urban Forestry estimates that it is responsible for about 235,800 trees, of which ap-

Figure 1—An enormous fig tree graces the grounds of Hawaiʻi's state capitol in Honolulu. Public trees in Honolulu provide great benefits, improving air quality, sequestering carbon dioxide, reducing stormwater runoff and beautifying the city. The trees of Honolulu return $2.98 in benefits for every $1 spent on tree care.

proximately 60% (~142,000) are along streets and 40% are in parks (~94,000) (Koike 2007). Because the Division of Urban Forestry is a unit of the City and County of Honolulu, the trees for which it is responsible are located not only in the city of Honolulu proper, but across Oahu. This analysis was conducted using an inventory that includes only 43,817 trees (*Table 1*; for a complete list see *Appendix A*), which may not be a representative sample of the population. With a few exceptions, this publication will address only the trees in the inventory.

The inventory contains 213 tree species with the rainbow shower tree (*Cassia* × *nealiae*), pink tecoma (*Tabebuia heterophylla*), and the coconut palm (*Cocos nucifera*) as the predominant species. The managers of Honolulu's urban forest can commend themselves for the diversity of their urban forest, in terms of both the number of species and distribution of trees among the species. This diversity will serve them well if faced with threats from invasive species, pests, and diseases.

The age structure of Honolulu's urban forest is heavily slanted towards young trees, with trees under 6 in in diameter at breast height (DBH) representing almost half of the population. Only 7.4% of the trees have a DBH greater than 18 in. Because older, larger trees provide the greatest level of environmental and other benefits, the scarcity of large trees means that the urban forest of Honolulu is not providing the full level of ecosystem services that could be expected.

Resource Function and Value

The municipal trees of Honolulu provide great benefits to the citizens. Their ability to moderate climate—thereby reducing energy use—is substantial. Electricity saved annually in Honolulu from both shading and climate effects of inventoried trees totals 1,943 MWh ($343,356) or $8 per tree.

Citywide, annual carbon dioxide (CO_2) sequestration and emission reductions due to energy savings by inventoried trees are 1,683 and 1,796 tons, respectively. CO_2 released during decomposition and tree care activities is 139 tons. Net CO_2 reduction is 3,340 tons, valued at $22,314 or $0.51 per tree. The inventoried trees of Honolulu store 25,529 tons of CO_2.

Net annual air pollutants removed, released, and avoided average 0.41 lb per tree and are valued at $47,365 or $1.08 per tree. Ozone is the most significant pollutant intercepted by trees, with 8,345 lb per year removed from the air ($12,268), while sulfur dioxide is the most economically significant air pollutant whose production is avoided at the power plant, due to reduced energy needs (13,096 lb per year; $19,907).

Honolulu's inventoried municipal trees intercept rain, reducing stormwater runoff by 35 million gal annually, with an estimated value of $350,104. Citywide, the average tree intercepts 798 gal of stormwater each year, valued at $7.99 per tree.

The estimated total annual benefits associated with aesthetics, property value increases, and other less tangible improvements are approximately $3.16 million or $72 per tree on average.

Annual benefits total $3.9 million and average $90 per tree. The inventory's 3,326 rainbow shower trees produce the highest total level of benefits (10.9% of total benefits). On a per tree basis, the monkeypod is the most valuable species, with benefits of $238 per tree. Species providing the least benefits on an individual tree basis include the Alexandra palm ($9) and Paraguay tea ($15).

Honolulu spends approximately $1.3 million in a typical year maintaining its inventoried trees ($30/tree). The highest single cost in the tree care budget is for infrastructure repair (estimated for inventoried trees at about $765,000), followed by pruning ($372,000).

Honolulu's municipal trees are a valuable asset, with those in the inventory alone providing approximately $2.6 million or $60 per tree ($2.88 per capita) in net annual benefits to the community.

Over the years, Honolulu has invested millions in its urban forest. Citizens are now receiving a return on that investment—trees are providing $2.98 in benefits for every $1 spent on tree care. Honolulu's benefit-cost ratio of 2.98 exceeds those reported for San Francisco (1.00), Berkeley, CA (1.37), Charleston, SC (1.34), Minneapolis, MN (1.57), Fort Collins, CO (2.18), Glendale, AZ (2.41), but is below those reported for Charlotte, NC (3.25) and New York City, NY (5.80).

Another way of describing the worth of trees is their replacement value, which assumes that the value of a tree is equal to the cost of replacing it in its current condition. Replacement value is a function of the number, stature, placement and condition of the cities' trees and reflects their value over a lifetime. As a central component of Honolulu green infrastructure, the 43,817 trees in the inventory are estimated to have a replacement value of $72.5 million or $1,665 per tree.

Resource Management

Honolulu's municipal trees are a dynamic resource. Managers of the urban forest and the community alike can take pride in knowing that municipal trees do improve the quality of life in Honolulu. The resource, however, is fragile and needs constant care to maximize and sustain the benefits through the future. To achieve resource sustainability Honolulu should consider the following recommendations:

1. Maintain the excellent condition of the trees by sustaining the current level of care.
2. Increase public acceptance of trees with an awareness campaign describing the environmental and other benefits that trees provide.
3. Many more trees are removed each year than are planted. Increasing the planting rate will help maintain a sustainable urban forest into the future.
4. Maintain the great species diversity, while avoiding invasive species. Consider planting more native species to provide "sanctuaries" for threatened species and habitat for native fauna.
5. Work with city planners to plan for trees in advance in areas of new development, especially along streets and in parking lots.
6. Plant large species where conditions are suitable to maximize benefits.

The challenge ahead is to better integrate Honolulu's green infrastructure with its gray infrastructure. This can be achieved by including green space and trees in the planning phase of development projects, providing adequate space for trees, and designing and maintaining plantings to maximize net benefits over the long term. By acting now to implement these recommendations, Honolulu will benefit from a more functional and sustainable urban forest in the future.

Chapter One—Introduction

Honolulu is undoubtedly one of America's favorite cities, and trees play a special role in creating the beautiful environment that so many people want to visit and call home. The City's Division of Urban Forestry of the Department of Parks and Recreation considers the more than 235,000 trees it manages to be an integral component of the city's urban infrastructure. The City believes that the public's investment in stewardship of the urban forest produces benefits that far outweigh the costs to the community and that investing in Honolulu's green infrastructure makes sense economically, environmentally, and socially.

Research indicates that healthy city trees can mitigate impacts associated with urban environs: polluted stormwater runoff, poor air quality, high requirements for energy for heating and cooling buildings, and heat islands. Healthy public trees increase real estate values, provide neighborhood residents with a sense of place, and foster psychological, social, and physical health. Street and park trees are associated with other intangibles, too, such as increasing community attractiveness for tourism and business and providing wildlife habitat and corridors. The urban forest makes Honolulu a more enjoyable place to live, work and play, while mitigating the city's environmental impact (*Figure 2*).

In an era of decreasing public funds and rising costs, however, there is a need to scrutinize public expenditures that are often viewed as "nonessential," such as planting and maintaining street and park trees. Some may question the need for the level of service presently provided. Hence, the primary question that this study asks is whether the

Figure 2—The urban forest makes Honolulu a more enjoyable place to live, work and play, while mitigating the city's environmental impact.

accrued benefits from Honolulu's urban trees justify the annual expenditures.

In answering this question, information is provided to do the following:

- Assist decision-makers to assess and justify the degree of funding and type of management program appropriate for Honolulu's urban forest.
- Provide critical baseline information for evaluating program cost-efficiency and alternative management structures.
- Highlight the relevance and relationship of Honolulu's municipal tree resource to local quality of life issues such as environmental health, economic development, and psychological well-being.
- Provide quantifiable data to assist in developing alternative funding sources through utility purveyors, air quality districts, federal or state agencies, legislative initiatives, or local assessment fees.

This report includes six chapters and three appendices:

Chapter One—Introduction: Describes the purpose of the study.

Chapter Two—Honolulu's Municipal Tree Resource: Describes the current structure of the urban forest.

Chapter Three—Costs of Managing Honolulu's Municipal Trees: Details management expenditures for publicly managed trees.

Chapter Four—Benefits of Honolulu's Municipal Trees: Quantifies the estimated value of tangible benefits and calculates net benefits and a benefit–cost ratio.

Chapter Five—Management Implications: Evaluates relevancy of this analysis to current programs and describes management challenges for tree maintenance.

Chapter Six—Conclusions: Final word on the use of this analysis.

Appendix A—Tree Distribution: Lists species and tree numbers in the street tree population.

Appendix B—Species Nativeness: Identifies species as native or nonnative, and characterizes their invasiveness.

Appendix C—Replacement Values: Lists replacement values for the entire municipal tree population.

Appendix D—Describes procedures and methodology for calculating structure, function, and value of the urban tree resource.

References—Lists publications cited in the study.

Chapter Two—Honolulu's Municipal Tree Resource

The trees of Honolulu are a living representation of the majesty and history of Hawaiʻi. Many have their roots in faraway lands, like the kukui tree (*Aleurites moluccana*), which was brought to the islands more than a thousand years ago in the canoes of the Polynesians, or the date palm (*Phoenix* spp.), brought by Bostonian Congressional missionaries (Outdoor Circle 1991). The sculptural monkeypod trees (*Samanea saman*) gracing the parks, the mahogany trees (*Swietenia mahogani*) arching over the boulevards of downtown Honolulu, the enormous Chinese and Indian figs (*Ficus microcarpa* and *F. benghalensis*), and the endlessly colorful flowers of the pea family (Fabaceae) give the city a character unlike any other (*Figure 3*).

Honolulu's trees are not only majestic and beautiful, but they constitute a thriving urban forest. In a recent study comparing urban forests of 18 cities nationwide (McPherson 2007), Honolulu was one of only three cities to score an "A" for its structure. The high score reflected the Division of Urban Forestry's efforts to build a strong resource with good age distribution, stocking levels, tree condition, and importance values.

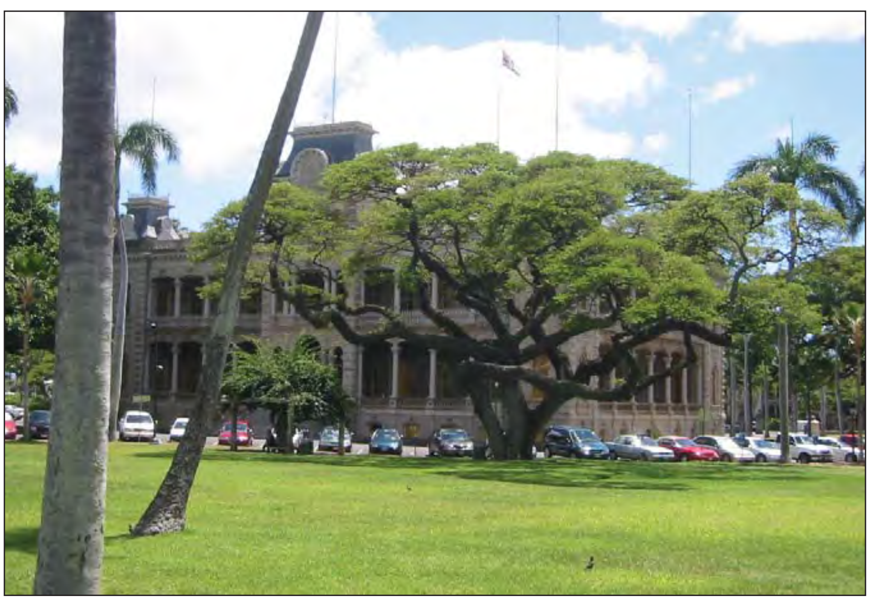

Figure 3—The trees of Hawaiʻi are a living representation of the state's majesty and history. Here palm trees and monkeypods adorn the Iolani Palace, the home of the Hawaiian Kingdom's last two monarchs.

Tree Numbers

The Division of Urban Forestry estimates that it is responsible for about 235,800 trees, of which approximately 60% (~142,000) are planted along streets and 40% are in parks (~94,000) (Koike 2007). Because the Division of Urban Forestry is a unit of the City and County of Honolulu, the trees for which it is responsible are located not only in the city of Honolulu proper, but across the island of Oahu. This analysis was conducted using a partial inventory that includes only 43,817 trees (*Table 1*; for a complete list see *Appendix A*), which may not be a representative sample of the population. With a few exceptions, this publication will address only the trees in the inventory.

Of the nearly 44,000 in the inventory, only about one-fourth are deciduous (i.e., in a typical year, they spend at least some amount of time without leaves). The trees that do lose their leaves typically do so after periods of drought rather than at a specific time of the year. More than half of the trees are broadleaf evergreen species (24,737) and about 7,000 are palms. Conifers represent the smallest category—only about 1,700—and nearly half of these are unauthorized plantings of Oriental arborvitae (*Platycladus orientalis*).

Street Tree Stocking Level

Although the inventory on which our study is based is not complete and did not sample empty street-tree planting sites across Oahu to determine stocking level, stocking can be estimated based on total street miles and the city's estimate of 141,480 street trees. Assuming there are 1,933 linear miles of streets in Honolulu (Koike

Table 1*—Most abundant municipal tree species from a recent partial inventory in order of predominance by DBH class and tree type.*

	DBHClass(in)										% of
Species	**0-3**	**3-6**	**6-12**	**12-18**	**18-24**	**24-30**	**30-36**	**36-42**	**>42**	**Total**	**total**
Broadleaf deciduous large (BDL)											
Giant crapemyrtle	221	449	538	382	20	1	-	-	-	1,611	3.7
Monkeypod	5	17	109	518	307	217	109	54	40	1,376	3.1
BDL OTHER	110	206	342	565	132	28	6	3	3	1,395	3.2
Total	336	672	989	1,465	459	246	115	57	43	4,382	10.0
Broadleaf deciduous medium (BDM)											
Rainbow shower tree	593	742	1,165	741	77	8	-	-	-	3,326	7.6
Golden shower	13	57	198	180	17	2	-	-	-	467	1.1
BDM OTHER	58	193	323	158	72	17	2	1	1	825	1.9
Total	664	992	1,686	1,079	166	27	2	1	1	4,618	10.5
Broadleaf deciduous small (BDS)											
Royal poinciana	28	69	284	583	149	19	6	1	-	1,139	2.6
BDS OTHER	38	33	54	20	7	-	-	-	-	152	0.3
Total	66	102	338	603	156	19	6	1	-	1,291	2.9
Broadleaf evergreen large (BEL)											
Pink tecoma	247	484	1,219	947	114	8	1	-	-	3,020	6.9
Silver trumpet tree	152	328	673	154	2	-	-	-	-	1,309	3.0
Paperbark	10	82	302	271	72	10	4	-	-	751	1.7
Allspice	198	307	190	20	1	-	-	-	-	716	1.6
Golden trumpet tree	73	151	281	154	13	1	-	-	-	673	1.5
Kou	116	186	161	31	2	-	-	-	-	496	1.1
Ironwood	2	52	35	87	135	65	30	32	9	447	1.0
BEL OTHER	303	622	580	637	318	217	104	34	37	2,852	6.5
Total	1,101	2,212	3,441	2,301	657	301	139	66	46	10,264	23.4
Broadleaf evergreen medium (BEM)											
Fern tree	294	429	703	345	4	-	-	-	-	1,775	4.1
Satinleaf	111	306	512	322	5	-	-	-	1	1,257	2.9
Kamani	92	161	200	56	44	29	35	1	-	618	1.4
Mamalis	41	101	313	114	3	-	-	-	-	572	1.3
Unidentified	126	144	157	101	26	10	2	1	-	567	1.3
BEM OTHER	237	640	620	334	48	8	5	5	5	1,902	4.3
Total	901	1,781	2,505	1,272	130	47	42	7	6	6,691	15.3
Broadleaf evergreen small (BES)											
Geiger tree	522	897	305	4	-	-	-	-	-	1,728	3.9
Silver buttonwood	338	472	234	96	16	6	-	-	-	1,162	2.7
False olive	239	325	389	169	10	-	-	-	-	1,132	2.6
Paraguay-tea	129	368	318	20	1	-	-	-	-	836	1.9
Plumeria	134	359	248	13	-	-	-	-	-	754	1.7
BES OTHER	654	787	539	173	12	3	2	-	-	2,170	5.0
Total	2,016	3,208	2,033	475	39	9	2	-	-	7,782	17.8

Species	DBHClass(in)									Total	% of total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42		
Conifer evergreen large (CEL)											
Oriental arborvitae	287	459	89	3	-	-	-	-	-	838	1.9
CEL OTHER	292	232	262	85	24	5	-	-	-	900	2.1
Total	579	691	351	88	24	5	-	-	-	1,738	4.0
Palm evergreen large (PEL)											
Coconut palm	55	80	1,038	1,476	8	-	-	-	-	2,657	6.1
PEL OTHER	1	4	1	1	1	-	-	-	-	8	0.0
Total	56	84	1,039	1,477	9	-	-	-	-	2,665	6.1
Palm evergreen medium (PEM)											
PEM OTHER	42	76	135	160	22	3	-	-	-	438	1.0
Total	42	76	135	160	22	3	-	-	-	438	1.0
Palm evergreen small (PES)											
Manila palm	396	1,225	67	9	1	1	-	-	-	1,699	3.9
Sago palm	523	24	56	84	-	-	-	-	-	687	1.6
Alexandra palm	42	326	147	-	-	-	-	-	-	515	1.2
PES OTHER	224	496	255	67	4	-	1	-	-	1,047	2.4
Total	1,185	2,071	525	160	5	1	1	-	-	3,948	9.0
Citywide Total	6,946	11,889	13,042	9,080	1,667	658	307	132	96	43,817	100.0

2007), on average there are 73 street trees per street mile. A fully stocked city would have one tree on each side of the street every 50 ft or 211 trees per street mile. By this measure, Honolulu's street tree stocking level is 35%, and there is room, theoretically, for as many as another 265,000 trees. The actual number of street tree planting sites may be significantly less due to inadequate planting spaces, the presence of privately owned trees, and utility conflicts. Honolulu's stocking level compares favorably with Charlotte, NC (23%), Cheyenne, WY (12%), and Glendale, AZ (9%) (McPherson et al. 2005b, 2005c, Peper et al. 2004), and is close to the mean stocking level for 22 U.S. cities (38.4%) (McPherson and Rowntree 1989).

Street Trees Per Capita

Calculating street trees per capita is another way of describing how well-forested a city is. Assuming a human population of 905,000 and a street tree population of 141,480 (Koike 2007), Honolulu's number of street trees per capita is 0.16—approximately one tree for every six people—significantly below the mean ratio of 0.37 reported for 22 U.S. cities (McPherson and Rowntree 1989).

Tree Canopy

Canopy cover, or more precisely, the amount and distribution of leaf surface area, is the driving force behind the urban forest's ability to produce benefits for the community. As canopy cover increases, so do the benefits afforded by leaf area. It is important to remember that street and park trees throughout the United States—and those of Honolulu—likely represent less than 20% of the entire urban forest (Moll and Kollin 1993). The tree canopy in Honolulu represented by trees in the inventory is estimated at 386 acres and shades approximately 2.74% of paved surfaces. Although the trees in the inventory are not necessarily representative of the whole street tree population, we can use the proportion of trees in the inventory to the whole street tree population to tentatively estimate the street tree canopy at 1,246 acres.

Species Richness, Composition and Diversity

The inventoried tree population in Honolulu includes an astounding mix of 213 different species—four times the mean of 53 species reported by McPherson and Rowntree (1989) in their survey of street tree populations in 22 U.S. cities. This broad diversity reflects both the generally good growing conditions and the wide range of microclimates across the island, which create different environmental niches for different species. Rainfall, for instance, varies from 17 to 160 in per year across the island, providing habitats for everything from drought-tolerant trees to rainforest species.

The predominant municipal tree species are the rainbow shower tree (*Cassia × nealiae*, 7.6%), pink tecoma (*Tabebuia heterophylla*, 6.9%), and the coconut palm (*Cocos nucifera*, 6.0%) (*Table 1*; see also *Appendix A*). The Division of Urban Forestry has done a very good job of diversifying their species choice, conforming to the general idea that no single species should represent more than 10% of the population and no genus more than 20% (Clark et al. 1997). Having one very dominant species is of concern because of the impact that drought, disease, pests, or other stressors can have on the urban forest. Providing a wide variety of species reduces the loss of canopy during catastrophic events.

The value of diversity has become increasingly clear to the residents of Hawai‘i as the trees of one genus—*Erythrina*—have recently been devasted by the erythrina gall wasp (*Quadrastichus erythrinae*). The wasp was first discovered in Hawai‘i on the island of Oahu in April 2005 and has quickly afflicted the population of native wiliwili trees (*Erythrina sandwicensis*) as well as introduced varieties on all the major islands (State of Hawai‘i Department of Agriculture 2006). Had *Erythrina* made up more than a small part of the population, the effects of the pest would have been even more devastating.

Invasive nonnative species

More than 4,600 species of plants have been introduced to the Hawaiian islands in the last 200 years. Although few become serious pests (one study puts the number at 86, or less than 2%; Smith 1998), those that do are a grave threat to the fragile ecosystem of the Hawaiian islands. Invasive species can destroy native ecosystems, displace native plants, disturb habitats for native fauna, and increase fire risk (Smith 1998).

Not all nonnative plant species are dangerous; many have great economic or aesthetic value and pose little risk to the Hawaiian ecosystem. The difficulty lies in distinguishing between the two. Currently, 79 species are defined as “noxious weeds” under Hawaiian state law (State of Hawai‘i 1992). This list, however, is almost certainly out of date and works retrospectively, i.e., it includes only plants that have already caused significant damage.

Several organizations, including the University of Hawai‘i, the USDA Forest Service, the Hawai‘i Department of Land and Natural Resources, and the Hawaiian Ecosystems at Risk project, are working to identify dangerous nonnative species before they become pests. The Department of Land and Natural Resources (DNLR) publishes the list “Hawai‘i’s Most Invasive Horticultural Plants” (DLNR 2007). A joint project by scientists at the University of Hawai‘i and the USDA Forest Service, called the Hawai‘i/Pacific Weed Risk Assessment, attempts to estimate the likeliness that a plant will become invasive based on published data (Daehler et al. 2004). These scientists are also beginning to make use of local information and local sources to improve predictions in a project called the Hawai‘i Exotic Plant Evaluation Protocol (Denslow and Daehler 2007). The Hawaiian Ecosystems at Risk project is a good source of information on the weed risk assessments and nonnative species in general (http://www.hear.org/).

The Honolulu inventory includes only eight native species, representing less than 3% of the population (for a complete list, see *Appendix B*), and only four of these species are proper trees. Thirty-three species (11% of the population) in the inventory are considered to be among Hawai‘i's most invasive by the DNLR (DNLR 2007) or have been rated as high risk or documented as causing significant ecological or economic harm by the Hawai‘i/Pacific Weed Risk Assessment project (HPWRA 2007). Ninety-three species (60% of the population) have been judged to pose little threat to native ecosystems. No information is available for the remaining 79 species (27% of the population).

Species Importance

Importance values (IV) are particularly meaningful to managers because they indicate a community's reliance on the functional capacity of particular species. For this study, IV takes into account not only total tree numbers, but canopy cover and leaf area, providing a useful comparison with the total population distribution.

Importance value (IV), a mean of three relative values, ranges between 0 and 100, where an IV of 100 implies total reliance on one species and an IV of 0 suggests no reliance. Urban tree populations with one dominant species (IV>25%) may have low

Table 2—*Importance values (IV) indicate which species dominate the population based on numbers and size*

Species	No. of trees	% of total trees	Leaf area (ft^2)	% of total leaf area	Canopy cover (ft^2)	% of total canopy cover	Importance value
Monkeypod	1,376	3.1	3,338,535	9.0	2,516,500	15.0	9.0
Rainbow shower tree	3,326	7.6	3,835,701	10.3	1,490,602	8.9	8.9
Pink tecoma	3,020	6.9	2,206,107	5.9	730,824	4.3	5.7
Coconut palm	2,657	6.1	2,456,426	6.6	698,807	4.2	5.6
Giant crapemyrtle	1,611	3.7	1,418,942	3.8	628,829	3.7	3.7
Fern tree	1,775	4.1	1,544,524	4.2	501,344	3.0	3.7
Satinleaf	1,257	2.9	1,371,963	3.7	435,073	2.6	3.1
Royal poinciana	1,139	2.6	791,086	2.1	637,265	3.8	2.8
Geiger tree	1,728	3.9	321,705	0.9	160,293	1.0	1.9
Manila palm	1,699	3.9	351,141	0.9	107,023	0.6	1.8
Silver trumpet tree	1,309	3.0	382,755	1.0	213,160	1.3	1.8
Golden trumpet tree	673	1.5	613,075	1.7	328,689	2.0	1.7
Ironwood	447	1.0	865,146	2.3	284,815	1.7	1.7
Golden shower	467	1.1	732,145	2.0	293,720	1.7	1.6
False olive	1,132	2.6	349,818	0.9	196,747	1.2	1.6
Kamani	618	1.4	628,892	1.7	249,218	1.5	1.5
Silver buttonwood	1,162	2.7	245,384	0.7	146,473	0.9	1.4
Mamalis	572	1.3	623,446	1.7	200,655	1.2	1.4
Paperbark	751	1.7	402,643	1.1	140,158	0.8	1.2
Oriental arborvitae	838	1.9	379,898	1.0	103,046	0.6	1.2
Plumeria	754	1.7	320,186	0.9	146,310	0.9	1.2
Allspice	716	1.6	236,559	0.6	154,962	0.9	1.1
Paraguay-tea	836	1.9	114,654	0.3	89,761	0.5	0.9
Kou	496	1.1	165,297	0.4	72,810	0.4	0.7
Sago palm	687	1.6	85,707	0.2	24,066	0.1	0.6
Alexandra palm	515	1.2	109,279	0.3	30,453	0.2	0.6
Other trees	12,256	28.0	13,237,664	35.6	6,220,198	37.0	33.5
Total	43,817	100.0	37,128,704	100.0	16,801,798	100.0	100.0

maintenance costs due to the efficiency of repetitive work, but may still incur large costs if decline, disease, or senescence of the dominant species results in large numbers of removals and replacements. When IVs are more evenly dispersed among five to ten leading species, the risks of a catastrophic loss of a single dominant species are reduced. Of course, suitability of the dominant species is an important consideration. Planting short-lived or poorly adapted trees can result in short rotations and increased long-term management costs.

The 26 most abundant municipal tree species listed in *Table 2* constitute 72% of the total population, 64% of the total leaf area, and 63% of total canopy cover, for an IV of 66.5. As *Table 2* illustrates, the functional value of the urban forest is well-distributed in Honolulu, with no one species supplying more than 10%. This is in sharp contrast to other cities, where the great importance of a tree might not be reflected in its numbers. In Albuquerque, NM, for instance, Siberian elms (*Ulmus pumila*) account for less than 7% of all public trees, but because of the trees' large size, the amount of leaf area and canopy cover they provide, their importance value is 27 (Vargas et al. 2006).

A few Honolulu species have larger IVs than their numbers would suggest. The monkeypod tree makes up only 3.1% of the population but, because of its great size, has an IV of 9. The opposite is sometimes also true. The Geiger tree (*Cordia sebestena*), for example, makes up 3.9% of the population, but because of its small leaf area, it has an IV of only 1.9.

Age Structure

The distribution of ages within a tree population influences present and future costs as well as the flow of benefits. An uneven-aged population allows managers to allocate annual maintenance costs uniformly over many years and assures continuity in overall tree canopy cover. A desirable distribution has a high proportion of new transplants to offset establishment-related mortality, while the percentage of older trees declines with age (Richards 1982/83).

The overall age structure, represented here in terms of DBH, for municipal trees in Honolulu appears skewed towards younger trees, with only 7.4% of trees (not including palms) having a DBH greater than 18 inches (*Figure 4*). Of these, more than one-quarter belong to one species, the monkeypod tree. Because older, larger trees provide the greatest level of environmental and other benefits, the scarcity of large trees means that the urban forest of Honolulu is not providing the full level of ecosystem services that it could.

The reason for the dearth of large trees is not entirely clear. The mortality rate of public trees in Honolulu is not high, estimated at 1% annually during the establishment period and 0.4% annually after that (Oka 2006). The mortality rate, however, is only

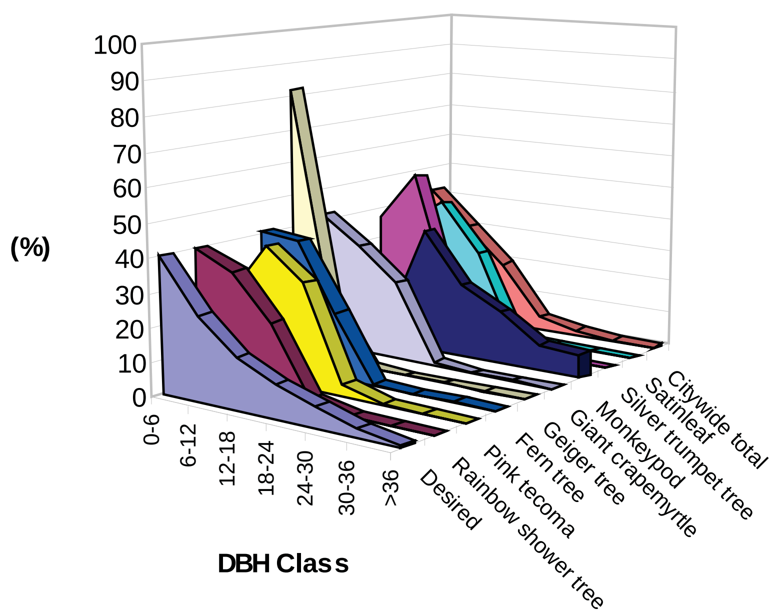

Figure 4—Relative age distribution for Honolulu's most common municipal tree species citywide shown with an ideal distribution.

an estimate of the number of trees that succumb to pests, disease or difficult conditions; it does not reflect trees that are intentionally removed. One significant problem facing the Division of Urban Forestry is the removal of trees by residents. According to the city's urban forester, residents are unhappy with the "mess" created by fallen leaves and flowers and often dig up the trees not long after they are planted, meaning that few have the opportunity to grow old.

Tree Condition

Tree condition indicates both how well trees are managed and how well they perform given site-specific conditions. Overall, the condition of trees in Honolulu is very good, with 70% in excellent or good shape (*Figure 5*). Condition varies greatly from species to species, however. The palms are in the best health, with all palm species having more than 90% in good or excellent condition. Poorer performers include pink tecomas, geiger trees, and paraguay teas (*Ilex paraguariensis*), of which fewer than half are in good or excellent condition.

Care should be taken when analyzing tree condition to ensure that relevant factors such as age are taken into consideration. For instance, the rainbow shower tree appears to be doing quite well. By comparing *Figure 5* with *Figure 4*, however, it is clear that most of the rainbow shower trees are relatively young and therefore have not yet stood the test of time. Conclusions about their suitability to the region should be postponed until the trees have matured. Nevertheless, a look at the condition of the monkeypod tree (with nearly 90% in good or excellent condition) suggests that even very old, large trees in Honolulu can do quite well.

Replacement Value

Replacement value is a way of describing the value of trees at a given time, reflecting their current number, stature, placement, and condition. There are several methods that arborists employ to develop a fair and reasonable perception of a tree's value (CTLA 1992, Watson 2002). The cost approach is widely used today and assumes that value equals the cost of production, or in other words, the cost of replacing a tree in its current state (Cullen 2002).

Replacing the 43,817 street trees in the inventory with trees of similar size, species, and condition, if,

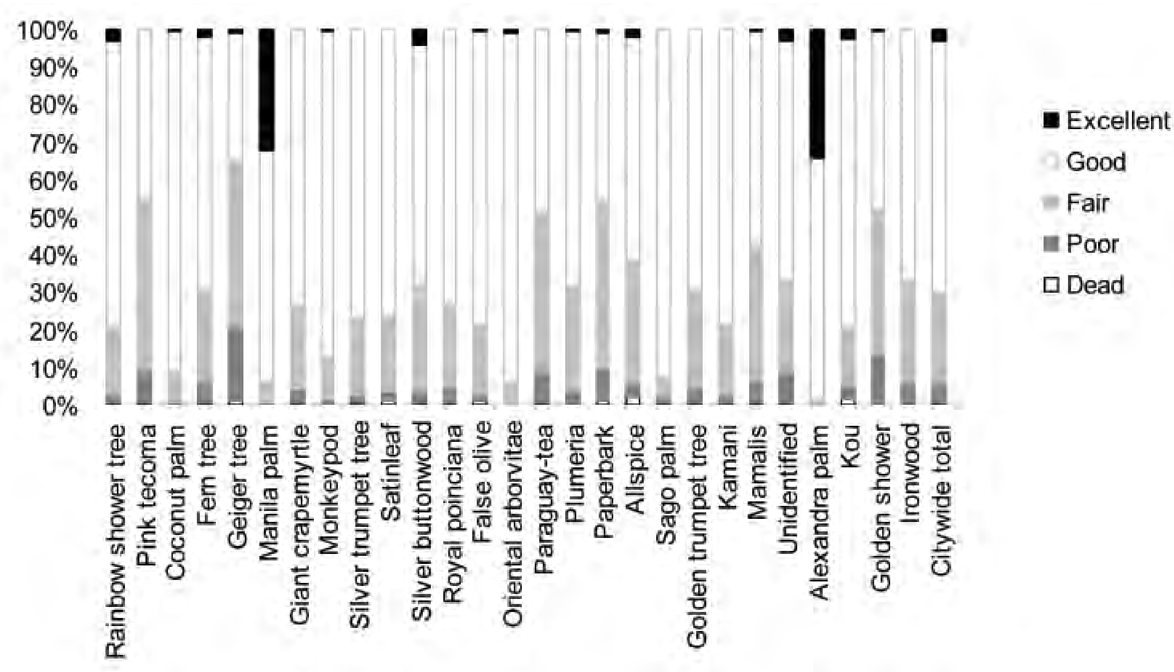

Figure 5—Condition of municipal trees in Honolulu by species.

for example, all were destroyed by a catastrophic storm, would cost approximately $72.5 million (*Table 3*; see also *Appendix C*). Considered this way, we can see that Honolulu's municipal trees are a valuable legacy and are a central component of the city's green infrastructure. The average replacement value per tree is $1,655. Monkeypod trees account for more than 17% of the total.

Replacement value should be distinguished from the value of annual benefits produced by the urban forest. The latter will be described in Chapter Four as a "snapshot" of benefits during one year, while the former accounts for the historical investment in trees over their lifetimes. Hence, the replacement value of Honolulu's municipal tree population is many times greater than the value of annual benefits it produces.

Table 3*—Replacement values, summed by DBH class, for the 22 most valuable species. See Appendix C for complete listing.*

	DBH class (in)									
Species	**0-6**	**6-12**	**12-18**	**18-24**	**24-30**	**30-36**	**36-42**	**>42**	**Total**	**% of Total**
Monkeypod	8,866	170,319	2,132,656	2,424,668	2,828,561	2,143,367	1,342,048	1,237,283	12,287,767	16.9
Rainbow shower tree	417,010	2,147,588	3,716,002	757,658	102,677	-	-	-	7,140,935	9.8
West Indian mahogany	530	17,810	111,996	385,513	837,238	828,738	466,241	251,293	2,899,358	4.0
Pink tecoma	165,950	769,697	1,496,260	350,711	36,973	6,148	-	-	2,825,739	3.9
Giant crapemyrtle	250,393	813,805	1,574,488	154,980	13,506	-	-	-	2,807,172	3.9
Fern tree	248,165	1,044,778	1,346,217	28,090	-	-	-	-	2,667,251	3.7
Royal poinciana	23,781	253,205	1,371,474	665,856	138,820	62,533	16,075	-	2,531,744	3.5
Satinleaf	163,849	786,124	1,296,184	33,902	-	-	-	23,019	2,303,078	3.2
Ironwood	18,490	31,477	196,267	576,641	454,302	319,735	383,527	124,335	2,104,774	2.9
Coconut palm	63,091	702,405	1,232,574	8,375	-	-	-	-	2,006,446	2.8
False olive	180,080	735,967	880,482	104,344	-	-	-	-	1,900,873	2.6
Silver trumpet tree	183,597	1,031,699	635,080	16,467	-	-	-	-	1,866,843	2.6
Kamani	54,995	214,273	159,966	233,455	285,944	510,273	20,514	-	1,479,421	2.0
Pink and white shower	55,120	93,930	330,668	616,978	198,468	18,133	25,312	41,777	1,380,385	1.9
Silver buttonwood	249,479	404,769	460,820	157,988	88,095	-	-	-	1,361,152	1.9
Golden shower	25,305	312,315	777,517	155,902	29,365	-	-	-	1,300,404	1.8
Paperbark	24,846	236,351	568,201	310,343	73,304	46,220	-	-	1,259,266	1.7
Golden trumpet tree	82,986	420,609	606,339	107,033	13,506	-	-	-	1,230,474	1.7
Manila palm	910,204	53,528	9,159	1,128	796	-	-	-	974,817	1.3
Geiger tree	378,916	453,809	16,678	-	-	-	-	-	849,403	1.2
Coral tree species	7,515	39,964	371,995	310,231	60,018	31,267	16,075	-	837,063	1.2
Pink shower	12,630	100,155	511,988	154,183	17,214	-	-	-	796,169	1.1
Other species	3,110,828	5,314,342	4,973,817	1,815,968	1,169,813	587,270	273,319	470,027	17,715,384	24.4
Citywide total	6,636,627	16,148,917	24,776,830	9,370,413	6,348,601	4,553,684	2,543,110	2,147,733	72,525,916	100.0

Chapter Three—Costs of Managing Honolulu's Municipal Trees

The benefits that Honolulu's trees provide come, of course, at a cost. This chapter presents a breakdown of annual expenditures for fiscal year July 2005–June 2006. To provide the most complete picture, we will consider first the budget as a whole and then the proportion of costs that can be attributed to the trees in the inventory (for more information on cost determination, see *Appendix D*). Total annual tree-related expenditures for Honolulu's municipal forestry program (all 235,800 trees) are currently approximately $5.4 million (Oka 2006; *Table 4*). The share of the budget spent on the inventoried trees is estimated to be $1.3 million.

The city spends about $23 per tree on average during the year, close to the 2003 mean value of $21.51 per tree reported for 256 California cities after adjusting for inflation (Thompson 2006). However, non-program expenditures (e.g., sidewalk repair, litter clean-up) were not included in the California survey. The average cost per tree for the inventoried trees, all of which are located along streets, is higher ($30) because infrastructure repair costs were not evenly divided amongst all trees but were attributed entirely to street trees. Honolulu's annual expenditure for the inventoried trees is approximately equal to that of Charleston, SC ($35) and New York City ($37), higher than Charlotte, NC ($21) or Bismarck, ND ($18), and is far less than some communities such as Santa Monica, CA ($53), and Berkeley, CA ($65) (McPherson et al. 2006; Peper et al. 2007; McPherson et al. 2005b, 2004a, 2005a, 2005d, respectively).

Forestry program expenditures fall into three general categories: tree planting and establishment, pruning and general tree care, and administration.

Tree Planting and Establishment

Quality nursery stock, careful planting, and follow-up care are critical to perpetuation of a healthy urban forest. In a typical year, the Division of Urban Forestry plants about 150 15- to 25-gal trees. Tree planting activities for the entire urban forest, including materials, labor, administration, and equipment costs as well as establishment watering, account for 4.6% of the program budget or approximately $250,000 ($1.06 per tree). Planting and establishment costs for the trees in the inventory are estimated at $46,456.

Pruning, Removals, and General Tree Care

Pruning accounts for more than one-third of the total annual expenditures, at $2 million ($8.48 per tree). All but emergency pruning is carried out by contractors, who give new trees a training prune once or twice in the first 3 years. Small and large trees are pruned at approximately the same frequency. Pruning costs for the inventoried trees are estimated to be $371,645. In last fiscal year, 44,386 trees were pruned.

***Table 4**—Honolulu's annual municipal forestry-related expenditures. The total budget and the costs attributed to the inventoried trees are shown.*

		Inventoried trees		
Expenditures	**Entire population ($)**	**Total ($)**	**$/Tree**	**$/Capita**
Purchasing trees and planting	250,000	46,456	1.06	0.05
Contract pruning	2,000,000	371,645	8.48	0.41
Removal	300,000	55,747	1.27	0.06
Administration	300,000	55,747	1.27	0.06
Inspection/service	95,000	17,653	0.40	0.02
Infrastructure repairs	2,467,890	764,317	17.44	0.84
Other costs	20,000	3,716	0.08	0.00
Total expenditures	5,432,890	1,315,281	30.02	1.45

Tree and stump removal accounts for about 5.5% of tree-related expenses ($300,000) for the entire urban forest. About 1,000 trees total are removed by contractors each year. Removal of trees in the inventory was estimated to cost $55,747.

Inspecting trees for damage and disease costs approximately $95,000 per year for all of the trees in the inventory. The share of these costs for the inventoried trees is approximately $17,653.

Administration

About $320,000 is spent annually on administration and other expenses, including salaries, equipment, training and supplies. The share of these costs for the inventoried trees is approximately $59,463.

Other Tree-Related Expenditures

The biggest fraction (45%) of the budget goes toward infrastructure repairs of sidewalks, gutters, roads and sewer pipes due to damage by tree roots. Although these costs are borne by another department, they should be considered tree-related. The total budget for infrastructure repair for the City and County of Honolulu is about $3.3 million of which 75% is estimated to be tree-related. Therefore, the budget for repairs for the entire urban forest is approximately $2.5 million. These costs were attributed only to street trees (~60% of the population) as park trees have a much smaller impact on infrastructure; the average infrastructure repair cost per street tree was $17.44. The share of the total costs for the inventoried trees (all on streets) is approximately $764,317.

Chapter Four—Benefits of Honolulu's Municipal Trees

City trees work ceaselessly, providing ecosystem services that directly improve human health and quality of life. In this section, the benefits of Honolulu's municipal trees are described. It should be noted that this is not a full accounting because some benefits are intangible or difficult to quantify (e.g., impacts on psychological and physical health, crime, and violence). Also, our limited knowledge about the physical processes at work and their interactions makes these estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Tree growth and mortality rates are highly variable. A true and full accounting of benefits and costs must consider variability among sites throughout the city (e.g., tree species, growing conditions, maintenance practices), as well as variability in tree growth.

For these reasons, the estimates given here provide first-order approximations of tree value. Our approach is a general accounting of the benefits produced by municipal trees in Honolulu—an accounting with an accepted degree of uncertainty that can nonetheless provide a platform from which decisions can be made (Maco and McPherson 2003). Methods used to quantify and price these benefits are described in more detail in *Appendix D*.

It should be noted again that this estimate of benefits applies only to the 43,817 trees in the inventory. Unfortunately, because the inventory does not represent a statistically random sample of the population, it is not possible to extrapolate directly from the values given here for the inventoried trees to the urban forest as a whole. It is clear, however, that the total benefits are at least several times those given here.

Energy Savings

Trees modify climate and conserve energy in three principal ways:

- Shading reduces the amount of radiant energy absorbed and stored by built surfaces.
- Transpiration converts moisture to water vapor and thus cools the air by using solar energy that would otherwise result in heating of the air.
- Wind-speed reduction reduces the movement of outside air into interior spaces and conductive heat loss where thermal conductivity is relatively high (e.g., glass windows) (Simpson 1998).

Trees and other vegetation within building sites may lower air temperatures 5°F (3°C) compared to outside the greenspace (Chandler 1965). At the larger scale of city-wide climate (6 miles or 10 km square), temperature differences of more than 9°F (5°C) have been observed between city centers and more vegetated suburban areas (Akbari et al. 1992). The relative importance of these effects depends on the size and configuration of trees and other landscape elements (McPherson 1993). Tree spacing, crown spread, and vertical distribution of leaf area influence the transport of warm air and pollutants along streets and out of urban canyons.

Trees reduce air movement into buildings and conductive heat loss from buildings. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Decreasing wind speed reduces heat transfer through conductive materials as well. *Appendix D* provides additional information on specific contributions that trees make toward energy savings.

Electricity Results

Electricity saved annually in Honolulu from both shading and climate effects equals 1,943 MWh ($343,356) (*Table 5*) or a citywide average of $7.84 per tree. Monkeypod trees provide 10.6% of the energy savings although they account for only 3.1% of total tree numbers, as expected for a tree species with the highest importance value (IV). Rainbow shower trees make the next greatest contribution to overall energy savings (9.4%). On a per tree basis,

Table 5—Net annual energy savings produced by the inventoried trees in Honolulu.

Species	Total electricity (MWh)	Electricity ($)	% of total tree numbers	% of total $	Avg. $/tree
Rainbow shower tree	182	32,245	7.6	9.4	9.69
Pink tecoma	100	17,624	6.9	5.1	5.84
Coconut palm	94	16,658	6.1	4.8	6.27
Fern tree	69	12,116	4.1	3.5	6.83
Geiger tree	19	3,403	3.9	1.0	1.97
Manila palm	12	2,120	3.9	0.6	1.25
Giant crapemyrtle	75	13,221	3.7	3.8	8.21
Monkeypod	205	36,240	3.1	10.6	26.34
Silver trumpet tree	28	4,902	3.0	1.4	3.75
Satinleaf	59	10,403	2.9	3.0	8.28
Silver buttonwood	16	2,756	2.7	0.8	2.37
Royal poinciana	71	12,523	2.6	3.7	10.99
False olive	27	4,804	2.6	1.4	4.24
Oriental arborvitae	12	2,197	1.9	0.6	2.62
Paraguay-tea	12	2,162	1.9	0.6	2.59
Plumeria	17	2,983	1.7	0.9	3.96
Paperbark	19	3,439	1.7	1.0	4.58
Allspice	19	3,283	1.6	1.0	4.59
Sago palm	2	372	1.6	0.1	0.54
Golden trumpet tree	42	7,390	1.5	2.2	10.98
Kamani	35	6,199	1.4	1.8	10.03
Mamalis	27	4,820	1.3	1.4	8.43
Alexandra palm	4	646	1.2	0.2	1.26
Kou	9	1,633	1.1	0.5	3.29
Golden shower	36	6,392	1.1	1.9	13.69
Ironwood	45	8,037	1.0	2.3	17.98
Other street trees	706	124,787	28.0	36.3	10.33
Citywide total	1,943	343,356	100.0	100.0	7.84

monkeypods again are the greatest contributors, reducing energy needs by approximately $26 per tree annually. Ironwood (*Casuarina equisetifolia*) and golden shower (*Cassia fistula*) provide the next greatest savings on a per tree basis ($18 and $14).

Atmospheric Carbon Dioxide Reduction

Urban forests can reduce atmospheric carbon dioxide in two ways:

- Trees directly sequester CO_2 as woody and foliar biomass as they grow.
- Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production and consumption of natural gas.

At the same time, however, CO_2 is released by vehicles, chain saws, chippers, and other equipment during the process of planting and maintaining trees. Also, eventually all trees die and most of the CO_2 that has accumulated in their woody biomass is released into the atmosphere as they decompose unless it is recycled. These factors must be taken into consideration when calculating the carbon dioxide benefits of trees.

Avoided and Sequestered Carbon Dioxide

Honolulu's inventoried trees reduce atmospheric

CO_2 by a net of 3,340 tons annually (*Table 6*). This benefit was valued at $22,314 or $0.51 per tree. Avoided CO_2 emissions from power plants due to energy savings totaled 1,796 tons, while CO_2 sequestered by trees was 1,683 tons. CO_2 released through decomposition and tree care activities totaled 139 tons, or 4% of the net total benefit. Avoided emissions are important in Honolulu because oil, which has a relatively high CO_2 emissions factor, accounts for almost all of the fuel used in power plants that generate electricity there (99.7%, US EPA 2003). Shading by trees during summer reduces the need for air conditioning, resulting in reduced use of oil for electricity generation.

On a per tree basis, ironwood ($1.82) and monkeypod ($1.80) provide the greatest CO_2 benefits (*Table 6*). Because of their age and great size, monkeypods also provide the greatest total CO_2 benefits, accounting for 11% of citywide CO_2 reduction.

Stored Carbon Dioxide

Trees also serve as a carbon sink, storing the carbon they have sequestered over a lifetime. The inventoried trees of Honolulu store about 25,519 tons of CO_2, thereby playing a valuable role in fighting global climate change (*Table 7*). Again, the monkeypod has the largest cumulative effect, providing 12.2% of the benefit. On a per tree basis, however,

***Table 6**—CO_2 reductions, releases, and net benefits produced by the inventoried trees in Honolulu.*

Species	Sequestered (lb)	Decomp. release (lb)	Maint. release (lb)	Avoided (lb)	Net total (lb)	Total ($)	% of trees	% of total $	Avg. $/tree
Rainbow shower tree	317,405	−11,753	−8,215	337,358	634,794	2,120	7.6	9.5	0.64
Pink tecoma	316,970	−11,359	−9,019	184,388	480,979	1,606	6.9	7.2	0.53
Coconut palm	64,979	−3,316	−9,517	174,286	226,433	756	6.1	3.4	0.28
Fern tree	161,776	−5,903	−4,145	126,766	278,494	930	4.1	4.2	0.52
Geiger tree	40,803	−754	−2,264	35,608	73,393	245	3.9	1.1	0.14
Manila palm	33,311	−999	−1,918	22,184	52,577	176	3.9	0.8	0.10
Giant crapemyrtle	147,083	−5,187	−3,971	138,322	276,248	923	3.7	4.1	0.57
Monkeypod	391,306	−19,978	−8,507	379,160	741,981	2,478	3.1	11.1	1.80
Silver trumpet tree	60,132	−2,157	−3,004	51,291	106,262	355	3.0	1.6	0.27
Satinleaf	69,594	−4,763	−3,299	108,839	170,371	569	2.9	2.5	0.45
Silver buttonwood	86,308	−1,949	−1,982	28,832	111,209	371	2.7	1.7	0.32
Royal poinciana	79,817	−4,203	−4,611	131,023	202,026	675	2.6	3.0	0.59
False olive	110,833	−3,009	−2,396	50,261	155,689	520	2.6	2.3	0.46
Oriental arborvitae	6,833	−74	−993	22,991	28,757	96	1.9	0.4	0.11
Paraguay−tea	17,414	−789	−1,493	22,623	37,755	126	1.9	0.6	0.15
Plumeria	33,432	−823	−1,260	31,205	62,554	209	1.7	0.9	0.28
Paperbark	112,013	−3,915	−2,697	35,980	141,380	472	1.7	2.1	0.63
Allspice	22,898	−757	−1,102	34,352	55,391	185	1.6	0.8	0.26
Sago palm	14,925	−336	−452	3,893	18,029	60	1.6	0.3	0.09
Golden trumpet tree	68,352	−2,149	−1,761	77,322	141,764	473	1.5	2.1	0.70
Kamani	45,031	−3,246	−1,902	64,856	104,739	350	1.4	1.6	0.57
Mamalis	35,017	−2,088	−1,516	50,427	81,840	273	1.3	1.2	0.48
Alexandra palm	8,190	−380	−651	6,764	13,922	47	1.2	0.2	0.09
Kou	15,714	−466	−881	17,081	31,448	105	1.1	0.5	0.21
Golden shower	60,543	−2,514	−1,535	66,872	123,367	412	1.1	1.9	0.88
Ironwood	178,964	−16,114	−2,700	84,089	244,239	816	1.0	3.7	1.82
Other street trees	866,506	−54,663	−32,257	1,305,573	2,085,158	6,964	28.0	31.2	0.58
Citywide total	3,366,149	−163,644	−114,050	3,592,344	6,680,798	22,314	100.0	100.0	0.51

Table 7—CO_2 storage by the inventoried trees in Honolulu.

Species	Total stored CO_2 (lbs)	Total ($)	% of trees	% of total $	Avg. $/tree
Rainbow shower tree	3,662,942	12,234	7.6	7.2	3.68
Pink tecoma	3,547,140	11,847	6.9	6.9	3.92
Coconut palm	1,029,163	3,437	6.1	2.0	1.29
Fern tree	1,838,162	6,139	4.1	3.6	3.46
Geiger tree	229,676	767	3.9	0.4	0.44
Manila palm	312,341	1,043	3.9	0.6	0.61
Giant crapemyrtle	1,617,323	5,402	3.7	3.2	3.35
Monkeypod	6,240,414	20,843	3.1	12.2	15.15
Silver trumpet tree	672,447	2,246	3.0	1.3	1.72
Satinleaf	1,485,846	4,963	2.9	2.9	3.95
Silver buttonwood	601,678	2,010	2.7	1.2	1.73
Royal poinciana	1,312,938	4,385	2.6	2.6	3.85
False olive	940,434	3,141	2.6	1.8	2.77
Oriental arborvitae	22,761	76	1.9	0.0	0.09
Paraguay-tea	244,988	818	1.9	0.5	0.98
Plumeria	255,001	852	1.7	0.5	1.13
Paperbark	1,223,273	4,086	1.7	2.4	5.44
Allspice	235,058	785	1.6	0.5	1.10
Sago palm	104,997	351	1.6	0.2	0.51
Golden trumpet tree	670,827	2,241	1.5	1.3	3.33
Kamani	1,013,451	3,385	1.4	2.0	5.48
Mamalis	651,456	2,176	1.3	1.3	3.80
Alexandra palm	118,801	397	1.2	0.2	0.77
Kou	144,180	482	1.1	0.3	0.97
Golden shower	785,373	2,623	1.1	1.5	5.62
Ironwood	5,035,557	16,819	1.0	9.9	37.63
Other street trees	8,046,952	56,920	28.0	33.4	4.70
Citywide total	51,038,012	170,467	100.0	100.0	3.89

ironwood trees are more than twice as valuable at $38 vs. $15 for monkeypod.

Air Quality Improvement

Urban trees improve air quality in five main ways:

- Absorbing gaseous pollutants (ozone, nitrogen oxides) through leaf surfaces
- Intercepting particulate matter (e.g., dust, ash, dirt, pollen, smoke)
- Reducing emissions from power generation by reducing energy consumption
- Releasing oxygen through photosynthesis
- Transpiring water and shading surfaces, resulting in lower local air temperatures, thereby reducing ozone levels

In the absence of the cooling effects of trees, higher temperatures contribute to ozone formation. On the other hand, most trees emit various biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes that can also contribute to ozone formation. The ozone-forming potential of different tree species varies considerably (Benjamin and Winer 1998). The contribution of BVOC emissions from city trees to ozone formation depends on complex geographic and atmospheric interactions that have not been studied in most cities.

Deposition and Interception

Each year 7.9 tons ($22,653) of nitrogen dioxide (NO_2), small particulate matter (PM_{10}), ozone (O_3), and sulfur dioxide (SO_2) is intercepted or absorbed by the inventoried trees (pollution deposition and particulate interception) in Honolulu (*Table 8*). Honolulu's trees are most effective at removing O_3 (8,345 lb) and PM_{10} (5,484 lb), with an implied annual value of $19,616. Again, due to their substantial leaf area, monkeypods contribute the most to pollutant uptake, removing more than 2,215 lbs each year.

Avoided Pollutants

Energy savings result in avoided air pollutant emissions of NO_2, PM_{10}, volatile organic compounds (VOCs), and SO_2 (*Table 8*). Together, 14.2 tons of pollutants are avoided annually with an implied value of $40,553. Avoided emissions of SO_2 are the most valuable (13,096 lb, $19,907) followed by NO_2 (11,488 lb, $16,888). Monkeypods have the greatest impact on reducing energy needs and therefore on avoiding pollutants; by moderating the climate they account for 3,004 lbs of pollutants whose production is avoided in power plants each year.

BVOC Emissions

Biogenic volatile organic compound (BVOC) emissions from trees must be considered. At a total of 13.2 tons, these emissions offset more than half of air quality improvements and are calculated as a cost to the city of $15,841. Nearly half (6.4 tons) of the emissions come from ironwood trees, an invasive nonnative species that should be avoided.

Net Air Quality Improvement

Net air pollutants removed, released, and avoided are valued at $47,365 annually. The average benefit per tree is $1.08 (0.41 lb). Trees vary dramatically in their ability to produce net air-quality benefits. Large-canopied trees with large leaf surface areas that are not high emitters, such as the monkeypod, produce the greatest benefits ($7,425 total; $5.40 per tree).

Stormwater Runoff Reductions

According to federal Clean Water Act regulations, municipalities must obtain a permit for managing their stormwater discharges into water bodies. Each city's program must identify the Best Management Practices (BMPs) it will implement to reduce its pollutant discharge. Trees are mini-reservoirs, controlling runoff at the source. Healthy urban trees can reduce the amount of runoff and pollutant loading in receiving waters in three primary ways:

- Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows.
- Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow.
- Tree canopies reduce soil erosion and surface transport by diminishing the impact of raindrops on barren surfaces.

Honolulu's inventoried trees intercept 35 million gal of stormwater annually, or 798 gal per tree on average (*Table 9*). The total value of this benefit to the city is $350,104, or $7.99 per tree.

Certain species are much better at reducing stormwater runoff than others. Leaf type and area, branching pattern and bark, as well as tree size and shape all affect the amount of precipitation trees can intercept and hold to reduce runoff. Trees that perform well include monkeypod ($29.65 per tree), ironwood ($13.91 per tree), and golden shower ($12.08 per tree). Poor performers are species with relatively small leaf and stem surface areas, in particular, the palms.

It should be noted that these values are based on the average annual rainfall recorded at the Honolulu airport (~17 in per year), which is one of the driest parts of the island. Stormwater interception benefits in rainier parts of Oahu will be greater.

Table 8*—*Pollutant deposition, avoided and BVOC emissions, and net air-quality benefits by predominant inventoried tree species in Honolulu.

	Deposition (lb)					Avoided (lb)					BVOC emissions		Total			
Species	O_3	NO_2	PM_1	SO_2	Total ($)	NO_2	PM_{10}	VOC	SO_2	Total ($)	(lb)	($)	(lb)	($)	% of trees	Avg. $/tree
Rainbow shower tree	709	90	458	82	1,913	1,079	182	182	1,230	3,808	−26	−16	3,986	5,706	7.6	1.72
Pink tecoma	382	49	249	44	1,034	590	99	99	672	2,082	−863	−518	1,322	2,598	6.9	0.86
Coconut palm	365	47	238	42	989	557	94	94	635	1,967	−1,197	−718	876	2,238	6.1	0.84
Fern tree	262	34	171	30	709	405	68	68	462	1,431	−3,248	−1,949	−1,747	191	4.1	0.11
Geiger tree	84	11	55	10	227	114	19	19	130	402	−1	−1	440	628	3.9	0.36
Manila palm	56	7	36	6	151	71	12	12	81	250	−145	−87	137	315	3.9	0.19
Giant crapemyrtle	267	33	174	31	721	442	75	75	504	1,561	0	0	1,601	2,283	3.7	1.42
Monkeypod	1,150	153	783	129	3,160	1,213	204	204	1,382	4,280	−27	−16	5,192	7,425	3.1	5.40
Silver trumpet tree	111	14	73	13	302	164	28	28	187	579	−171	−103	446	778	3.0	0.59
Satinleaf	227	29	148	26	616	348	59	59	397	1,229	−22	−13	1,271	1,831	2.9	1.46
Silver buttonwood	76	10	50	9	207	92	16	16	105	325	−4	−2	370	531	2.7	0.46
Royal poinciana	300	38	194	34	809	419	71	71	478	1,479	−7	−4	1,597	2,284	2.6	2.01
False olive	103	13	67	12	278	161	27	27	183	567	−6	−3	587	842	2.6	0.74
Oriental arborvitae	54	7	35	6	146	74	12	12	84	260	−64	−39	220	367	1.9	0.44
Paraguay−tea	47	6	31	5	127	72	12	12	82	255	0	0	268	382	1.9	0.46
Plumeria	76	10	50	9	207	100	17	17	114	352	−72	−43	320	516	1.7	0.68
Paperbark	73	9	48	8	198	115	19	19	131	406	−519	−312	−95	293	1.7	0.39
Allspice	81	10	53	9	219	110	19	19	125	388	−230	−138	196	469	1.6	0.66
Sago palm	13	2	8	1	34	12	2	2	14	44	−34	−21	20	57	1.6	0.08
Golden trumpet tree	172	22	112	20	465	247	42	42	282	873	−271	−163	667	1,175	1.5	1.75
Kamani	130	17	85	15	353	207	35	35	236	732	−575	−345	186	740	1.4	1.20
Mamalis	105	14	68	12	284	161	27	27	184	569	−10	−6	588	847	1.3	1.48
Alexandra palm	16	2	10	2	43	22	4	4	25	76	−45	−27	39	92	1.2	0.18
Kou	38	5	25	4	103	55	9	9	62	193	−1	−0	207	295	1.1	0.60
Golden shower	140	18	90	16	377	214	36	36	244	755	−5	−3	789	1,129	1.1	2.42
Ironwood	149	19	97	17	403	269	45	45	307	949	−12,795	−7,677	−11,847	−6,325	1.0	−14.15
Other street trees	3,160	410	2,075	361	8,577	4,175	704	704	4,760	14,738	−6,064	−3,638	10,285	19,677	28.0	1.62
Citywide total	8,345	1,081	5,484	953	22,653	11,488	1,937	1,937	13,096	40,553	−26,402	−15,841	17,920	47,365	100.0	1.08

***Table 9**—Annual stormwater reduction benefits of the inventoried trees in Honolulu.*

Species	Total rainfall interception (gal)	Total ($)	% of total tree numbers	% of Total $	Avg. $/tree
Rainbow shower tree	2,890,876	28,911	7.6	8.3	8.69
Pink tecoma	1,885,799	18,859	6.9	5.4	6.24
Coconut palm	1,876,509	18,766	6.1	5.4	7.06
Fern tree	1,367,114	13,672	4.1	3.9	7.70
Geiger tree	346,793	3,468	3.9	1.0	2.01
Manila palm	287,180	2,872	3.9	0.8	1.69
Giant crapemyrtle	1,172,960	11,730	3.7	3.3	7.28
Monkeypod	4,080,110	40,804	3.1	11.6	29.65
Silver trumpet tree	429,452	4,295	3.0	1.2	3.28
Satinleaf	1,135,475	11,356	2.9	3.2	9.03
Silver buttonwood	287,146	2,872	2.7	0.8	2.47
Royal poinciana	1,027,682	10,278	2.6	2.9	9.02
False olive	411,361	4,114	2.6	1.2	3.63
Oriental arborvitae	303,400	3,034	1.9	0.9	3.62
Paraguay-tea	148,768	1,488	1.9	0.4	1.78
Plumeria	306,040	3,061	1.7	0.9	4.06
Paperbark	345,367	3,454	1.7	1.0	4.60
Allspice	293,172	2,932	1.6	0.8	4.09
Sago palm	66,618	666	1.6	0.2	0.97
Golden trumpet tree	692,688	6,927	1.5	2.0	10.29
Kamani	504,766	5,048	1.4	1.4	8.17
Mamalis	520,942	5,210	1.3	1.5	9.11
Alexandra palm	84,816	848	1.2	0.2	1.65
Kou	167,117	1,671	1.1	0.5	3.37
Golden shower	564,197	5,642	1.1	1.6	12.08
Ironwood	621,936	6,220	1.0	1.8	13.91
Other street trees	13,189,650	131,906	28.0	37.7	10.91
Citywide total	35,007,932	350,104	100.0	100.0	7.99

Aesthetic, Property Value, Social, Economic and Other Benefits

Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, shade that increases human comfort, wildlife habitat, sense of place, and well-being are difficult to price (*Figure 6*). 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" intangible benefits, research that compares differences in sales prices of houses was used to estimate the contribution associated with trees. The difference in sales price re-

Figure 6—Trees add value to residential property.

flects the willingness of buyers to pay for the benefits and costs associated with trees. This approach has the virtue of capturing what buyers perceive as both the benefits and costs of trees in the sales price. One limitation of using this approach is the difficulty associated with extrapolating results from front-yard trees on residential properties to trees in other locations (e.g., commercial vs. residential) (see *Appendix D* for more details).

The estimated total annual benefit associated with property value increases and other less tangible benefits is $3.16 million, or $72 per tree on average (*Table 10*). Tree species that produce the highest average annual benefits include monkeypod ($175 per tree), Oriental arborvitae ($152), golden shower ($110 per tree), and rainbow shower tree ($107), while small trees, especially small palms, produce the least benefits (Alexandra palm $5.88, Paraguay tea $9.63).

Total Annual Net Benefits and Benefit–Cost Ratio (BCR)

Total annual benefits produced by Honolulu's inventoried trees are estimated at $3.9 million ($90 per tree, $4.33 per capita) (*Table 11*). Over the same period, tree-related expenditures are estimated to be $1.3 million ($30 per tree, $1.45 per capita). Net annual benefits (benefits minus costs) are $2.6 million, or $60 per tree and $2.88 per capita. The inventoried trees of the Honolulu municipal

Table 10—*Annual aesthetic and other benefits of the inventoried trees in Honolulu.*

Species	Total ($)	% of total tree numbers	% of total $	Avg. $/tree
Rainbow shower tree	357,533	7.6	11.3	107.50
Pink tecoma	165,329	6.9	5.2	54.74
Coconut palm	184,224	6.1	5.8	69.34
Fern tree	154,512	4.1	4.9	87.05
Geiger tree	73,793	3.9	2.3	42.70
Manila palm	32,083	3.9	1.0	18.88
Giant crapemyrtle	149,966	3.7	4.8	93.09
Monkeypod	240,140	3.1	7.6	174.52
Silver trumpet tree	42,832	3.0	1.4	32.72
Satinleaf	89,862	2.9	2.8	71.49
Silver buttonwood	35,346	2.7	1.1	30.42
Royal poinciana	44,099	2.6	1.4	38.72
False olive	48,293	2.6	1.5	42.66
Oriental arborvitae	127,684	1.9	4.0	152.37
Paraguay-tea	8,054	1.9	0.3	9.63
Plumeria	50,087	1.7	1.6	66.43
Paperbark	34,943	1.7	1.1	46.53
Allspice	37,649	1.6	1.2	52.58
Sago palm	32,385	1.6	1.0	47.14
Golden trumpet tree	53,369	1.5	1.7	79.30
Kamani	40,484	1.4	1.3	65.51
Mamalis	43,821	1.3	1.4	76.61
Alexandra palm	3,029	1.2	0.1	5.88
Kou	24,425	1.1	0.8	49.24
Golden shower	51,618	1.1	1.6	110.53
Ironwood	30,983	1.0	1.0	69.31
Other street trees	1,003,327	28.0	31.8	82.78
Citywide total	3,159,871	100.0	100.0	72.12

***Table 11**—Benefit–cost summary for inventoried public trees in Honolulu.*

Benefits	Total ($)	$/tree	$/capita
Energy	343,356	7.84	0.38
CO_2	22,314	0.51	0.02
Air Quality	47,365	1.08	0.05
Stormwater	350,104	7.99	0.39
Aesthetic/Other	3,159,871	72.12	3.49
Total benefits	3,923,010	89.53	4.33
Cost			
Planting	46,456	1.06	0.05
Contract pruning	371,645	8.48	0.41
Removal	55,747	1.27	0.06
Administration	55,747	1.27	0.06
Inspection/service	17,653	0.40	0.02
Infrastructure repairs	764,317	17.44	0.84
Other costs	3,716	0.08	0.00
Total costs	1,315,281	30.02	1.45
Net benefits	2,607,729	59.51	2.88
Benefit-cost ratio		2.98	

forest currently return $2.98 to the community for every $1 spent on management. Honolulu's benefit–cost ratio of 2.98 exceeds those reported for San Francisco (1.00), Berkeley, CA (1.37), Charleston, SC (1.34), Fort Collins, CO (2.18), Glendale, AZ (2.41), but is below those reported for Charlotte, NC (3.25) and New York City, NY (5.60) (Maco et al. 2003, 2005; McPherson et al. 2006, 2003, 2005c, 2005b; Peper et al. 2007, respectively).

Honolulu's municipal trees have beneficial effects on the environment, estimated at more than $750,000. Energy savings represents 45% of environmental benefits, with stormwater runoff reduction accounting for another 45%. Air quality improvement (6%) and carbon dioxide reduction (3%) provide the remaining environmental benefits. Annual increases in property value and other intangible benefits reflected in this are very valuable, accounting for 80% of total annual benefits in Honolulu.

Table 12 shows the distribution of total annual benefits in dollars for the predominant municipal tree species in Honolulu. By virtue of their numbers and relatively large size, rainbow shower trees provide the largest share of the inventoried trees (10.9%). Monkeypods are most valuable to the city on an individual tree basis ($238 per tree). It should be noted once again that this analysis provides benefits for a snapshot in time. As some of the larger-growing trees that have been planted recently, such as the pink tecoma and silver trumpet tree, move into larger size classes, they will provide increasingly greater benefits. Small-stature species, such as the Paraguay tea ($15 per tree) and the Alexandra palm ($9 per tree) provide correspondingly lower benefits.

This is not to argue that large trees are always the best option. Numerous considerations drive species choice, including planting site, potential conflicts with infrastructure, maintenance concerns, water use, and design considerations. In some cases, such as under power lines, small trees are the best or only option. Nonetheless, the results of this analysis emphasize that large trees should be planted wherever possible to increase benefits to the citizens of Honolulu.

Table 12—*Average annual benefits ($ per tree) of Honolulu municipal trees by species.*

Species	Energy	CO_2	Air quality	Stormwater	Aesthetic/other	Total	Total ($)	% of Total $
Rainbow shower tree	9.69	0.64	1.72	8.69	107.50	128.24	426,514	10.9
Pink tecoma	5.84	0.53	0.86	6.24	54.74	68.22	206,016	5.3
Coconut palm	6.27	0.28	0.84	7.06	69.34	83.79	222,643	5.7
Fern tree	6.83	0.52	0.11	7.70	87.05	102.21	181,422	4.6
Geiger tree	1.97	0.14	0.36	2.01	42.70	47.19	81,538	2.1
Manila palm	1.25	0.10	0.19	1.69	18.88	22.11	37,566	1.0
Giant crapemyrtle	8.21	0.57	1.42	7.28	93.09	110.57	178,122	4.5
Monkeypod	26.34	1.80	5.40	29.65	174.52	237.71	327,087	8.3
Silver trumpet tree	3.75	0.27	0.59	3.28	32.72	40.61	53,162	1.4
Satinleaf	8.28	0.45	1.46	9.03	71.49	90.71	114,020	2.9
Silver buttonwood	2.37	0.32	0.46	2.47	30.42	36.04	41,875	1.1
Royal poinciana	10.99	0.59	2.01	9.02	38.72	61.33	69,859	1.8
False olive	4.24	0.46	0.74	3.63	42.66	51.74	58,573	1.5
Oriental arborvitae	2.62	0.11	0.44	3.62	152.37	159.16	133,379	3.4
Paraguay-tea	2.59	0.15	0.46	1.78	9.63	14.61	12,213	0.3
Plumeria	3.96	0.28	0.68	4.06	66.43	75.40	56,855	1.4
Paperbark	4.58	0.63	0.39	4.60	46.53	56.73	42,601	1.1
Allspice	4.59	0.26	0.66	4.09	52.58	62.18	44,519	1.1
Sago palm	0.54	0.09	0.08	0.97	47.14	48.82	33,541	0.9
Golden trumpet tree	10.98	0.70	1.75	10.29	79.30	103.03	69,336	1.8
Kamani	10.03	0.57	1.20	8.17	65.51	85.47	52,820	1.3
Mamalis	8.43	0.48	1.48	9.11	76.61	96.10	54,971	1.4
Alexandra palm	1.26	0.09	0.18	1.65	5.88	9.05	4,662	0.1
Kou	3.29	0.21	0.60	3.37	49.24	56.71	28,129	0.7
Golden shower	13.69	0.88	2.42	12.08	110.53	139.60	65,193	1.7
Ironwood	17.98	1.82	−14.15	13.91	69.31	88.88	39,731	1.0
Other street trees	10.33	0.58	1.62	10.91	82.78	106.23	1,241,735	31.7
Citywide total	7.84	0.51	1.08	7.99	72.12	89.53	3,923,009	100.0

Chapter Five—Management Implications

Honolulu's urban forest reflects the values, lifestyles, preferences, and aspirations of current and past residents. It is a dynamic legacy whose character will change greatly over the next decades.

Although this study provides a "snapshot" in time of the resource, it also serves as an opportunity to speculate about the future. Given the status of Honolulu's municipal tree population, what future trends are likely and what management challenges will need to be met to sustain or increase this level of benefits? Focusing on three components—resource complexity, resource extent, and maintenance—will help refine broader municipal tree management goals. Achieving resource sustainability will produce long-term net benefits to the community while reducing the associated costs incurred in managing the resource.

Resource Complexity

The Honolulu Division of Urban Forestry is to be commended for its commitment to increasing the diversity of the urban forest. The number of species (213) is excellent, reflecting the good growing conditions as well as the wide range of microclimates across the island. As well, the distribution of trees across species, with no one species representing more than 10% of the total, will serve the citizens of Honolulu well, protecting their urban forest, and consequently the benefits they receive from it, from disease or pest infestations.

Age distribution is of some concern. There are very few large, old trees in the population, and because large trees provide the greatest benefits, the Division of Urban Forestry should strive to plant species that will be large at maturity. Half of all trees in the largest size classes (>30 in DBH) belong to only two species, monkeypod and ironwood, and very few trees of equal stature are being planted to replace them. Ironwood has been evaluated as invasive (HPWRA 2007), so another large species should be found to use as replacements as the ironwoods age and are removed. *Figure 7* shows the medium- and large-growing trees that are being planted in the greatest numbers. Few, if any, of these will have the stature and grandeur of the monkeypod.

Additionally, the Division of Urban Forestry should monitor the growth and survival of newly planted trees to determine the factors that are keeping trees from reaching mature size.

The urban forest managers of Honolulu should consider expanding the use of native species where possible. Less than 3% of the inventoried trees are native species and 11% are nonnatives that are

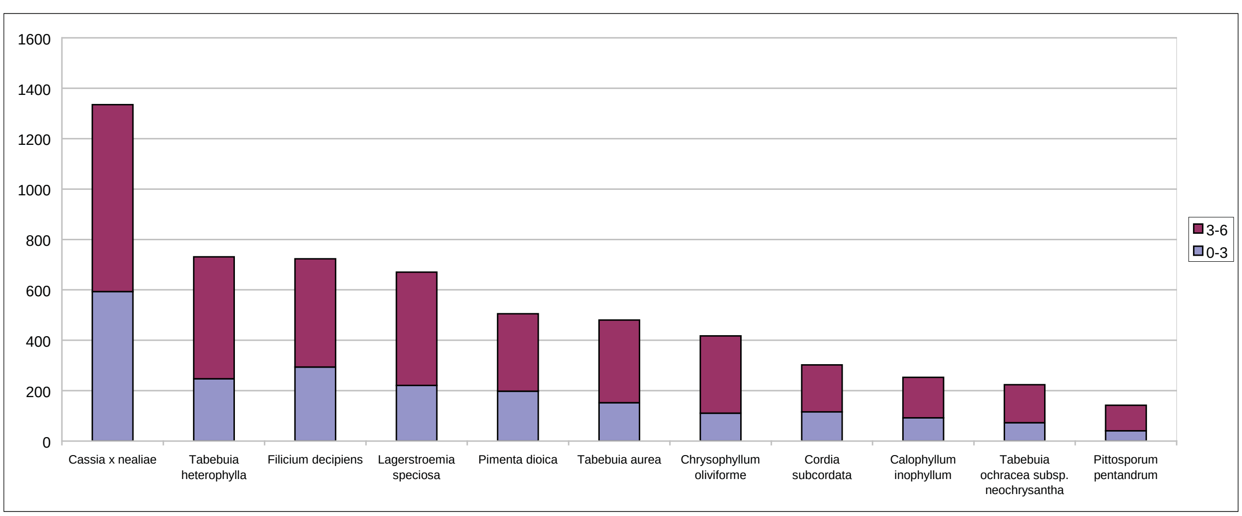

Figure 7—Medium and large-growing trees being planted in the greatest numbers.

known to be invasive. More than one-quarter of the trees belong to species whose risk of invasiveness has not been determined.

While native trees are definitely not always the best choice in urban environments, planting native trees where possible offers several advantages. (1) Native species are adapted to local conditions. Although in urban situations, the conditions do not necessarily correspond to those that the native plants evolved with, appropriate native species can be chosen to match existing urban conditions. Flood-tolerant species, for example, often make good street trees as their roots are adapted to survive in conditions of low oxygen. Drought-tolerant species also make good street trees as the small soil volume usually alloted to street trees means they often lack sufficient water. (2) Native species provide habitat and corridors for the movement and survival of native fauna. As native habitats are increasingly threatened across Oahu due to their extirpation by invasive species or by development, native birds, animals, and insects are left without habitat. Native species along roads and in patches throughout the city can provide a replacement for lost habitats to some extent. (3) As invasive plants threaten many native Hawaiian ecosystems and are on the verge of extirpating some local species, cities can serve as "sanctuaries" for threatened species. At the very least, invasive species should be removed where they are present and trees that are known to be non-invasive should be used as replacements.

Resource Extent

Canopy cover, or more precisely the amount and distribution of leaf surface area, is the driving force behind the urban forest's ability to produce benefits for the community. As the number of trees, and therefore canopy cover increases, so do the benefits afforded by leaf area. Maximizing the return on investment is contingent upon maximizing and maintaining the quality and extent of Honolulu's canopy cover.

Honolulu's estimated street tree stocking level is 35%, or 73 street trees per mile, with room, theoretically, for up to 265,000 more, although restricted space, conflicts with other uses, and the presence of privately owned trees will reduce that number. Although this stocking rate compares favorably with a number of cities, the ratio of newly planted trees to removals is cause for concern. In 2006, 1,054 trees were removed and only 156 were planted (Koike 2007). Unless trees are being planted by other entities, for example, by developers in areas of new construction, the ratio of seven trees removed for each one planted indicates that the urban forest is not sustainable.

According to Honolulu's urban forester, one of the Division of Urban Forestry's greatest difficulties in increasing the extent of the urban forest is public acceptance of trees (Oka 2006). Many residents consider trees "messy" and complain of the "fallen leaves and flowers." Increasing awareness of the many environmental and other benefits of trees should be one of the Division's goals. Otherwise, residents will continue to remove trees that have just been planted. The results of this study, describing the benefits of trees in dollar terms, might provide helpful information for a public awareness campaign.

Areas of new development offer good opportunities for increasing tree planting because trees can be planned for from the beginning. In Central Oahu alone, for example, a 25% increase in housing stock is anticipated over the next 20 years (City and County of Honolulu 2002). By working together with city planners and officials as well as the public, sufficient space can be allotted in new developments to allow trees room to grow. Parking lots offer another opportunity for expanding the urban forest. Many cities have adopted shade ordinances requiring a certain percentage of parking lot surfaces to be shaded (McPherson 2004).

When working to increase the extent of the urban forest, ways to maximize benefits should be kept in mind. Any tree added to a city adds benefits in terms of air quality improvement, climate moderation, reductions in energy use, stormwater management and aesthetic improvement—benefits that have been described in detail above. Planting trees along streets and in parking lots, however, offers additional benefits beyond those that come from planting trees in parks. Most importantly, trees located along streets and in parking lots are more likely to shade structures. By moderating the immediate climate around a building, energy use is reduced, lowering costs for building owners and simultaneously reducing air pollutants and CO_2.

Trees along streets have also been shown to reduce the wear on asphalt by lowering surface temperatures and thereby reducing maintenance costs (McPherson and Muchnick 2005). A study comparing several blocks in Modesto, CA, demonstrated that streets shaded by large trees required fewer than half the number of slurry seals (2.5 vs. 6 on an unshaded street) over a 30-year period, with associated savings of $0.66/ft^2. In areas with on-street parking, trees can have an additional benefit of reducing pollutant emissions from parked cars by lowering local air temperature (Scott et al. 1999). Evaporative emissions from non-operating vehicles account for 16% of total vehicular emissions; lowering the air temperature by increasing shade cover in Sacramento parking lots to 50% from 8% was estimated to reduce overall emissions by 2% (0.85 tons per day). Although seemingly modest, many existing programs to improve air quality have similar goals.

The importance of size in achieving high levels of benefits should also not be forgotten. Large species should be planted wherever possible.

Figure 8—Trees grow in very small planting spaces, increasing the likelihood of poor growth and survival and of damage to the sidewalk, while a few feet away a wide grassy area is available.

Maintenance

Maintenance of the trees themselves in Honolulu is very good. Pruning cycles in Honolulu are excellent and are reflected in the overall condition of the trees. Removal rates appear adequate as very few dead or dying trees were noted in the inventory (0.5%).

A more urgent maintenance concern for Honolulu is the conflict between trees and infrastructure. Infrastructure repairs account for nearly half of urban forest management costs. Such conflicts are sometimes unavoidable, especially in very urban areas, but creative measures can mitigate the damage. Sometimes solutions are overlooked. In *Figure 8*, for example, trees are growing in extremely small planting spaces, increasing the likelihood of poor growth, while a few feet away a wide grassy area is available.

In areas of new development or where streets and sidewalks are being replaced or substantially repaired, more room should be given to trees in medians and planting strips. Engineered soils can provide extra growing space for roots in areas where space is at a premium (CUFR 2007). In areas of existing plantings, techniques are available to allow trees to be preserved in many cases. Costello and Jones's *Reducing Infrastructure Damage by Tree Roots: A Compendium of Strategies* (2003) offers many suggestions including meandering sidewalks around roots or ramping them over the top, and rubber sidewalks.

Other Management Implications

One of the main difficulties standing in the way of the creation of a sustainable urban forest in Honolulu is the absence of sufficient data. A complete, updated inventory of all trees that the Division of Urban Forestry is responsible for is recommended. If possible, the inventory should include a tally of available planting spaces with a note of the size tree that could be planted there. In this way, spaces for large trees could be filled first, providing the most benefits in a cost-effective way. If an on-the-ground survey of planting spaces isn't feasible, a windshield inventory is a less expensive option, as is the use of remote sensing to determine available sites.

New plantings should also be closely monitored. Few trees seem to be reaching their full mature stature, and the reason for this remains unclear. Disease, poor species selection, unauthorized removals by residents, or insufficient soil volume to allow for full growth are a few possible explanations. A careful monitoring program will help the Division of Urban Forestry determine what changes need to be made to ensure that trees grow to their full size and provide maximum benefits.

Chapter Six—Conclusion

This analysis describes structural characteristics of the municipal tree population and uses tree growth and geographic data for Honolulu to model the ecosystem services trees provide the city and its residents. In addition, the benefit-cost ratio has been calculated and management needs identified. The approach is based on established tree sampling, numerical modeling, and statistical methods and provides a general accounting of the benefits produced by municipal trees in Honolulu that can be used to make informed decisions.

Honolulu's street trees are a valuable asset, with those in the inventory alone providing approximately $3.9 million ($90 per tree) in annual gross benefits. Benefits to the community are most pronounced for energy savings, stormwater interception, and aesthetic and other benefits. Thus, municipal trees play a particularly important role in maintaining the environmental and aesthetic qualities of the city. Honolulu spends approximately $1.3 million maintaining its inventoried trees or $30 per tree.

After costs are taken into account, Honolulu's inventoried tree resource provides approximately $2.6 million, or $60 per tree ($2.88 per capita) in net annual benefits to the community. Over the years, Honolulu has invested millions of dollars in its municipal forest. Citizens are seeing a return on that investment—receiving $2.98 in benefits for every $1 spent on tree care. The fact that Honolulu's benefit-cost ratio exceeds 1.0 indicates that the program is not only operationally efficient, but is capitalizing on the functional services its trees can produce. As the resource grows, continued investment in management is critical to insuring that residents will receive a high return on investment in the future.

Honolulu's municipal trees are a dynamic resource. Managers of the urban forest and the community alike can take pride in knowing that street and park trees do improve the quality of life in the city. However, the city's trees are also a fragile resource that needs constant care to maximize and sustain production of benefits into the future.

Six main management recommendations have been derived from this analysis:

1. Maintain the excellent condition of the trees by sustaining the current level of care.
2. Increase public acceptance of trees with an awareness campaign describing the environmental and other benefits that trees provide.
3. Many more trees are removed each year than are planted. Increasing the planting rate will help maintain a sustainable urban forest into the future.
4. Maintain the great species diversity, while avoiding invasive species and species whose risks have not been determined. Consider planting more native species to provide "sanctuaries" for threatened species and habitat for native fauna.
5. Work with city planners to plan for trees in advance in areas of new development, especially along streets and in parking lots.
6. Plant large species where conditions are suitable to maximize benefits.

These recommendations build on a history of dedicated management and commitment to natural resource preservation that has put Honolulu on course to provide an urban forest resource that is both functional and sustainable.

Appendix A—Tree Distribution

***Table A1**—Tree numbers by size class (DBH in inches) for all inventoried trees.*

	DBH class (in)									
Species	**0–3**	**3–6**	**6–12**	**12–18**	**18–24**	**24–30**	**30–36**	**36–42**	**>42**	**Total**
Broadleaf deciduous large (BDL)										
Lagerstroemia speciosa	221	449	538	382	20	1	-	-	-	1,611
Samanea saman	5	17	109	518	307	217	109	54	40	1,376
Erythrina species	2	25	53	166	72	8	3	1	-	330
Cassia grandis	13	29	63	133	20	1	-	-	-	259
Tabebuia species	62	88	62	26	3	-	-	-	-	241
Erythrina sandwicensis	3	17	41	86	7	12	-	-	-	166
Erythrina variegata	2	2	13	45	-	-	-	-	-	62
Tabebuia donnell-smithii	12	13	29	4	-	-	-	-	-	58
Pterocarpus indicus	-	1	6	38	7	4	-	1	-	57
Dalbergia species	1	1	23	13	7	-	-	-	-	45
Erythrina variegata v. *orientalis*	1	22	1	6	3	-	-	-	-	33
Ficus virens	1	-	6	10	4	2	1	-	-	24
Terminalia catappa	7	2	9	4	-	-	1	-	1	24
Tipuana tipu	-	1	6	13	-	-	-	-	-	20
Enterolobium cyclocarpum	-	-	2	8	-	-	-	-	2	12
Calycophyllum candidissimum	-	3	8	-	-	-	-	-	-	11
Platymiscium pinnatum	-	-	2	9	-	-	-	-	-	11
Pseudobombax ellipticum	1	-	9	-	1	-	-	-	-	11
Albizia lebbeck	2	-	-	2	4	1	-	1	-	10
Melia azedarach	1	-	7	1	1	-	-	-	-	10
Chorisia speciosa	1	-	1	-	1	-	-	-	-	3
Fraxinus uhdei	-	-	-	1	1	-	-	-	-	2
Polyalthia longifolia	-	-	1	-	1	-	-	-	-	2
Tabebuia impetiginosa	1	1	-	-	-	-	-	-	-	2
Cochlospermum vitifolium	-	-	-	-	-	-	1	-	-	1
Hura crepitans	-	1	-	-	-	-	-	-	-	1
Total	336	672	989	1,465	459	246	115	57	43	4,382
Broadleaf deciduous medium (BDM)										
Cassia x *nealiae*	593	742	1,165	741	77	8	-	-	-	3,326
Cassia fistula	13	57	198	180	17	2	-	-	-	467
Koelreuteria elegans	8	72	240	45	2	-	-	-	-	367
Cassia javanica	30	109	57	70	67	13	1	1	1	349
Jacaranda mimosifolia	2	3	22	42	2	-	1	-	-	72
Hibiscus tiliaceus	18	8	4	1	1	4	-	-	-	36
Annona reticulata	-	1	-	-	-	-	-	-	-	1
Total	664	992	1,686	1,079	166	27	2	1	1	4,618
Broadleaf deciduous small (BDS)										
Delonix regia	28	69	284	583	149	19	6	1	-	1,139
Schinus terebinthifolius	5	4	25	16	4	-	-	-	-	54
Annona squamosa	16	17	3	-	-	-	-	-	-	36
Lagerstroemia indica	8	6	5	3	2	-	-	-	-	24

Species	DBH class (in)									Total
	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	
Morus species	6	2	12	1	1	-	-	-	-	22
Tabebuia bahamensis	-	2	4	-	-	-	-	-	-	6
Cotinus coggygria	3	1	-	-	-	-	-	-	-	4
Euphorbia tirucalli	-	1	2	-	-	-	-	-	-	3
Morus nigra	-	-	2	-	-	-	-	-	-	2
Ficus carica	-	-	1	-	-	-	-	-	-	1
Total	66	102	338	603	156	19	6	1	-	1,291
Broadleaf evergreen large (BEL)										
Tabebuia heterophylla	247	484	1,219	947	114	8	1	-	-	3,020
Tabebuia aurea	152	328	673	154	2	-	-	-	-	1,309
Melaleuca quinquenervia	10	82	302	271	72	10	4	-	-	751
Pimenta dioica	198	307	190	20	1	-	-	-	-	716
Tabebuia ochracea subsp. *neochrysantha*	73	151	281	154	13	1	-	-	-	673
Cordia subcordata	116	186	161	31	2	-	-	-	-	496
Casuarina equisetifolia	2	52	35	87	135	65	30	32	9	447
Ficus benjamina	55	27	63	80	31	40	11	-	2	309
Spathodea campanulata	18	48	62	96	60	13	4	5	-	306
Aleurites moluccana	54	99	91	30	8	2	-	-	-	284
Swietenia mahogani	-	1	12	30	53	74	48	19	8	245
Heritiera littoralis	14	171	41	-	-	-	-	-	-	226
Acacia koa	19	94	45	16	3	1	-	-	-	178
Schefflera actinophylla	20	21	56	38	7	1	1	-	-	144
Catalpa longissima	-	-	3	41	50	40	7	1	-	142
Andira inermis	2	7	30	88	13	1	-	-	-	141
Peltophorum pterocarpum	-	-	7	43	24	21	7	2	-	104
Noronhia emarginata	19	52	26	-	-	-	-	-	-	97
Eucalyptus robusta	-	1	5	33	21	8	2	-	-	70
Ficus microcarpa	-	4	9	24	5	1	3	1	14	61
Mangifera indica	5	8	10	15	10	4	4	2	2	60
Persea americana	8	20	16	6	2	-	-	-	-	52
Tamarindus indica	9	23	5	1	1	1	2	-	-	42
Vitex parviflora	-	1	4	34	1	-	-	-	-	40
Ceratonia siliqua	-	2	20	9	2	-	-	-	-	33
Pithecellobium dulce	1	1	3	11	10	2	2	1	1	32
Ficus species	-	-	3	2	4	5	5	2	6	27
Prosopis pallida	-	2	2	8	3	3	6	1	1	26
Eucalyptus deglupta	3	4	8	8	2	-	-	-	-	25
Eucalyptus citriodora	1	3	13	4	1	-	-	-	-	22
Sesbania grandiflora	5	9	6	-	-	-	-	-	-	20
Ravenala madagascariensis	2	4	9	3	-	-	-	-	-	18
Eucalyptus species	15	1	1	-	-	-	-	-	-	17
Cinnamomum camphora	14	1	-	-	-	-	-	-	-	15
Grevillea robusta	-	-	-	9	5	-	1	-	-	15
Citrus x *paradisi*	3	2	7	-	-	-	-	-	-	12

Species	DBH class (in)									Total
	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	
Olea europaea	2	3	6	1	-	-	-	-	-	12
Averrhoa bilimbi	4	2	5	-	-	-	-	-	-	11
Macadamia integrifolia	3	3	2	2	-	-	-	-	-	10
Litchi chinensis	3	3	3	-	-	-	-	-	-	9
Artocarpus heterophyllus	5	-	1	-	-	-	-	-	-	6
Ficus benghalensis	3	-	-	-	1	-	-	-	2	6
Manilkara zapota	6	-	-	-	-	-	-	-	-	6
Artocarpus altilis	-	-	3	2	-	-	-	-	-	5
Ficus elastica	3	1	-	1	-	-	-	-	-	5
Ficus lyrata	-	-	3	1	1	-	-	-	-	5
Pimenta racemosa	2	2	-	-	-	-	-	-	-	4
Metrosideros polymorpha	3	-	-	-	-	-	-	-	-	3
Falcataria moluccana	1	-	-	-	-	-	1	-	-	2
Azadirachta indica	1	1	-	-	-	-	-	-	-	2
Fagraea berteroana	-	1	-	-	-	-	-	-	-	1
Ficus religiosa	-	-	-	-	-	-	-	-	1	1
Lagunaria patersonii	-	-	-	1	-	-	-	-	-	1
Total	1,101	2,212	3,441	2,301	657	301	139	66	46	10,264
Broadleaf evergreen medium (BEM)										
Filicium decipiens	294	429	703	345	4	-	-	-	-	1,775
Chrysophyllum oliviforme	111	306	512	322	5	-	-	-	1	1,257
Calophyllum inophyllum	92	161	200	56	44	29	35	1	-	618
Pittosporum pentandrum	41	101	313	114	3	-	-	-	-	572
Unidentified species	126	144	157	101	26	10	2	1	-	567
Citharexylum spinosum	56	201	114	23	2	2	-	-	-	398
Bauhinia purpurea	7	49	180	65	6	-	-	-	-	307
Cinnamomum verum	24	80	79	74	19	-	-	-	-	276
Harpephyllum caffrum	76	89	3	-	-	-	-	-	-	168
Callistemon viminalis	12	52	72	6	1	-	-	-	-	143
Bauhinia species	7	52	36	32	3	-	-	-	-	130
Acacia confusa	6	26	24	42	-	-	-	-	-	98
Bauhinia variegata	7	15	21	34	4	-	-	-	-	81
Thespesia populnea	1	16	24	18	2	1	-	-	-	62
Psidium guajava	16	25	6	-	-	-	-	-	-	47
Mimusops caffra	-	4	14	19	4	-	-	-	-	41
Cupaniopsis anacardioides	1	5	12	-	-	-	-	-	-	18
Moringa oleifera	1	3	8	5	1	-	-	-	-	18
Pandanus tectorius	2	4	11	-	1	-	-	-	-	18
Syzygium jambos	-	1	4	9	-	2	1	-	-	17
Erythrina crista-galli	2	3	8	2	-	-	-	-	-	15
Ficus macrophylla	-	-	-	-	1	2	2	5	5	15
Beaucarnea recurvata	13	-	-	-	-	-	-	-	-	13
Pittosporum arborescens	2	5	2	-	-	-	-	-	-	9
Schinus molle	-	-	-	2	4	1	2	-	-	9
Eugenia uniflora	1	3	-	-	-	-	-	-	-	4

Species	DBH class (in)									Total
	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	
Salix matsudana	2	2	-	-	-	-	-	-	-	4
Bixa orellana	1	2	-	-	-	-	-	-	-	3
Tournefortia argentea	-	1	-	2	-	-	-	-	-	3
Citrus sinensis	-	1	1	-	-	-	-	-	-	2
Amherstia nobilis	-	1	-	-	-	-	-	-	-	1
Colvillea racemosa	-	-	-	1	-	-	-	-	-	1
Pittosporum species	-	-	1	-	-	-	-	-	-	1
Total	901	1,781	2,505	1,272	130	47	42	7	6	6,691
Broadleaf evergreen small (BES)										
Cordia sebestena	522	897	305	4	-	-	-	-	-	1,728
Conocarpus erectus var. *argenteus*	338	472	234	96	16	6	-	-	-	1,162
Elaeodendron orientale	239	325	389	169	10	-	-	-	-	1,132
Ilex paraguariensis	129	368	318	20	1	-	-	-	-	836
Plumeria species	134	359	248	13	-	-	-	-	-	754
Bauhinia x blakeana	41	112	173	85	-	-	-	-	-	411
Clusia rosea	100	219	84	4	-	-	-	-	-	407
Harpullia pendula	292	80	22	4	-	-	-	-	-	398
Bauhinia hookeri	3	22	75	23	-	-	-	-	-	123
Carica papaya	47	47	5	-	-	-	-	-	-	99
Thevetia peruviana	4	51	15	3	-	-	-	-	-	73
Coccoloba uvifera	8	13	32	15	1	-	-	-	-	69
Guaiacum officinale	24	3	31	-	-	-	-	-	-	58
Magnolia grandiflora	11	33	12	1	-	-	-	-	-	57
Psidium cattleianum	37	10	4	1	2	-	-	-	-	54
Callistemon citrinus	5	22	13	10	-	-	-	-	-	50
Bougainvillea species	13	28	3	-	-	-	-	-	-	44
Tabernaemontana pandacaqui	5	27	8	4	-	-	-	-	-	44
Annona muricata	7	22	3	-	-	-	-	-	-	32
Dracaena species	8	12	9	-	-	-	-	-	-	29
Senna surattensis	6	16	-	-	-	-	-	-	-	22
Murraya paniculata	3	10	7	1	-	-	-	-	-	21
Bolusanthus speciosus	-	1	2	4	9	2	2	-	-	20
Schefflera pueckleri	-	-	7	13	-	-	-	-	-	20
Jatropha integerrima	5	13	1	-	-	-	-	-	-	19
Nerium oleander	4	3	9	1	-	-	-	-	-	17
Callistemon rigidus	2	4	7	-	-	-	-	-	-	13
Citrus species	4	8	1	-	-	-	-	-	-	13
Musa species	-	7	4	1	-	-	-	-	-	12
Morinda citrifolia	1	5	5	-	-	-	-	-	-	11
Citrus limon	1	8	1	-	-	-	-	-	-	10
Citrus reticulata	4	1	2	-	-	-	-	-	-	7
Gardenia species	1	6	-	-	-	-	-	-	-	7
Leucaena leucocephala	6	1	-	-	-	-	-	-	-	7
Ligustrum japonicum	4	1	-	1	-	-	-	-	-	6
Ochrosia elliptica	4	-	-	-	-	1	-	-	-	5

Species	DBH class (in)									Total
	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	
Citrus maxima	-	1	1	1	-	-	-	-	-	3
Ochna serrulata	1	1	1	-	-	-	-	-	-	3
Eriobotrya japonica	2	-	-	-	-	-	-	-	-	2
Carissa macrocarpa	-	-	1	-	-	-	-	-	-	1
Crescentia cujete	-	-	-	1	-	-	-	-	-	1
Hibiscus species	1	-	-	-	-	-	-	-	-	1
Parmentiera cereifera	-	-	1	-	-	-	-	-	-	1
Total	2,016	3,208	2,033	475	39	9	2	-	-	7,782
Conifer evergreen large (CEL)										
Platycladus orientalis	287	459	89	3	-	-	-	-	-	838
Podocarpus species	167	52	31	9	-	-	-	-	-	259
Cupressus sempervirens	38	91	99	19	2	-	-	-	-	249
Araucaria heterophylla	8	26	78	34	19	4	-	-	-	169
Podocarpus neriifolius	41	18	29	8	-	-	-	-	-	96
Cupressus species	21	23	1	-	-	-	-	-	-	45
Araucaria columnaris	5	5	11	12	3	-	-	-	-	36
Juniperus chinensis ‘Torulosa’	3	8	7	2	-	-	-	-	-	20
Pinus species	7	6	-	-	-	-	-	-	-	13
Pinus thunbergiana	1	1	6	-	-	-	-	-	-	8
Podocarpus usambarensis	-	2	-	-	-	-	-	-	-	2
Agathis vitiensis	-	-	-	1	-	-	-	-	-	1
Juniperus chinensis	-	-	-	-	-	1	-	-	-	1
Pinus pinea	1	-	-	-	-	-	-	-	-	1
Total	579	691	351	88	24	5	-	-	-	1,738
Palm evergreen large (PEL)										
Cocos nucifera	55	80	1,038	1,476	8	-	-	-	-	2,657
Syagrus romanzoffiana	-	3	1	-	-	-	-	-	-	4
Corypha utan	1	1	-	-	-	-	-	-	-	2
Orbignya cohune	-	-	-	-	1	-	-	-	-	1
Phoenix canariensis	-	-	-	1	-	-	-	-	-	1
Total	56	84	1,039	1,477	9	-	-	-	-	2,665
Palm evergreen medium (PEM)										
Roystonea regia	3	44	56	137	18	2	-	-	-	260
Palm species	38	31	47	15	1	-	-	-	-	132
Phoenix dactylifera	-	-	25	7	2	-	-	-	-	34
Phoenix species	1	1	6	-	-	-	-	-	-	8
Butia capitata	-	-	1	-	1	1	-	-	-	3
Syagrus coronata	-	-	-	1	-	-	-	-	-	1
Total	42	76	135	160	22	3	-	-	-	438
Palm evergreen small (PES)										
Veitchia merrillii	396	1,225	67	9	1	1	-	-	-	1,699
Cycas revoluta	523	24	56	84	-	-	-	-	-	687
Archontophoenix alexandrae	42	326	147	-	-	-	-	-	-	515
Dypsis lutescens	109	266	40	9	1	-	-	-	-	425
Pritchardia pacifica	30	87	80	4	-	-	-	-	-	201

Hyophorbe verschaffeltii	33	16	37	5	-	-	-	-	-	91
Hyophorbe lagenicaulis	7	31	20	23	3	-	-	-	-	84
Dypsis decaryi	8	24	20	12	-	-	-	-	-	64
Ptychosperma macarthurii	23	29	2	-	-	-	-	-	-	54
Phoenix roebelenii	1	27	20	-	-	-	-	-	-	48
Washingtonia robusta	4	1	18	13	-	-	-	-	-	36
Caryota mitis	5	12	2	-	-	-	-	-	-	19
Archontophoenix cunninghamiana	1	3	12	-	-	-	-	-	-	16
Livistona chinensis	2	-	4	1	-	-	-	-	-	7
Acoelorraphe wrightii	-	-	-	-	-	-	1	-	-	1
Chamaerops humilis	1	-	-	-	-	-	-	-	-	1
Total	1,185	2,071	525	160	5	1	1	-	-	3,948
Citywide total	6,946	11,889	13,042	9,080	1,667	658	307	132	96	43,817

Appendix B—Species Nativeness

Table B1—*Species nativeness and threat of invasiveness.*

Species	No. of trees	% of population	Reference
Native			
Acacia koa	178	0.41	Native
Erythrina sandwicensis	166	0.38	Native
Gardenia species	7	0.02	Native
Hibiscus species	1	0.00	Native
Hibiscus tiliaceus	36	0.08	Native
Metrosideros polymorpha	3	0.01	Native
Pittosporum species	1	0.00	Native
Platycladus orientalis	838	1.91	Native
Subtotal	1,230	2.8	Native
Invasive			
Acacia confusa	98	0.22	H2
Albizia lebbeck	10	0.02	H1
Aleurites moluccana	284	0.65	H1
Bauhinia purpurea	307	0.70	H1
Casuarina equisetifolia	447	1.02	H2
Cinnamomum camphora	15	0.03	H1
Cinnamomum verum	276	0.63	H1
Citharexylum spinosum	398	0.91	M1
Cupaniopsis anacardioides	18	0.04	E; M1
Eriobotrya japonica	2	0.00	E; M1
Eugenia uniflora	4	0.01	H2
Falcataria moluccana	2	0.00	H2
Ficus microcarpa	61	0.14	H2, M1
Grevillea robusta	15	0.03	E, H1; M1
Leucaena leucocephala	7	0.02	H1
Melaleuca quinquenervia	751	1.71	H1; MI
Melia azedarach	10	0.02	H1; M1
Morinda citrifolia	11	0.03	H2
Olea europaea	12	0.03	E; M1
Pimenta dioica	716	1.63	H1; M1
Pimenta racemosa	4	0.01	E; M1
Pithecellobium dulce	32	0.07	H1
Pittosporum pentandrum	572	1.31	M1
Psidium cattleianum	54	0.12	H2; M1
Psidium guajava	47	0.11	H2
Ptychosperma macarthurii	54	0.12	H1
Schinus molle	9	0.02	H1; M1
Schinus terebinthifolius	54	0.12	H2; M1
Senna surattensis	22	0.05	H2; M1
Spathodea campanulata	306	0.70	H1; M1
Thespesia populnea	62	0.14	H1
Thevetia peruviana	73	0.17	H1
Washingtonia robusta	36	0.08	H1

Species	No. of trees	% of population	Reference
Subtotal	4,769	10.9	
Noninvasive			
Andira inermis	141	0.32	L1
Annona muricata	32	0.07	L1
Annona squamosa	36	0.08	L1
Araucaria columnaris	36	0.08	L1
Araucaria heterophylla	169	0.39	L1
Archontophoenix cunninghamiana	16	0.04	L1
Artocarpus altilis	5	0.01	L1
Artocarpus heterophyllus	6	0.01	L1
Bauhinia variegata	81	0.18	L2
Bauhinia × *blakeana*	411	0.94	L2
Bixa orellana	3	0.01	L1
Bolusanthus speciosus	20	0.05	L1
Callistemon citrinus	50	0.11	L1
Callistemon rigidus	13	0.03	L1
Callistemon viminalis	143	0.33	L1
Carica papaya	99	0.23	L1
Cassia fistula	467	1.07	L1
Cassia grandis	259	0.59	L1
Cassia javanica	349	0.80	L1
Cassia × *nealiae*	3,326	7.59	L
Catalpa longissima	142	0.32	L1
Ceratonia siliqua	33	0.08	L1
Chorisia speciosa	3	0.01	L1
Chrysophyllum oliviforme	1,257	2.87	L1
Citrus limon	10	0.02	L1
Citrus maxima	3	0.01	L1
Citrus reticulata	7	0.02	L1
Citrus × *paradisi*	12	0.03	L1
Coccoloba uvifera	69	0.16	L
Cochlospermum vitifolium	1	0.00	L1
Colvillea racemosa	1	0.00	L1
Cordia sebestena	1,728	3.94	L1
Cordia subcordata	496	1.13	L1
Crescentia cujete	1	0.00	L1
Cycas revoluta	687	1.57	L1
Delonix regia	1,139	2.60	L1
Dracaena species	29	0.07	L1
Dypsis lutescens	425	0.97	L1
Elaeodendron orientale	1,132	2.58	L1
Enterolobium cyclocarpum	12	0.03	L1
Erythrina crista-galli	15	0.03	L1
Erythrina variegata	62	0.14	L1
Erythrina variegata var. *orientalis*	33	0.08	L1
Eucalyptus deglupta	25	0.06	L1

Species	No. of trees	% of population	Reference
Eucalyptus robusta	70	0.16	L1
Fagraea berteroana	1	0.00	L1
Ficus benghalensis	6	0.01	L1
Ficus carica	1	0.00	L1
Ficus elastica	5	0.01	L1
Ficus lyrata	5	0.01	L1
Ficus religiosa	1	0.00	L1
Guaiacum officinale	58	0.13	L1
Harpullia pendula	398	0.91	L1
Heritiera littoralis	226	0.52	L1
Hyophorbe lagenicaulis	84	0.19	L1
Hyophorbe verschaffeltii	91	0.21	L1
Jacaranda mimosifolia	72	0.16	L1
Jatropha integerrima	19	0.04	L1
Juniperus chinensis	1	0.00	L1
Juniperus chinensis 'Torulosa'	20	0.05	L1
Lagerstroemia indica	24	0.05	L1
Lagerstroemia speciosa	1,611	3.68	L1
Litchi chinensis	9	0.02	L1
Magnolia grandiflora	57	0.13	L1
Mangifera indica	60	0.14	L1
Moringa oleifera	18	0.04	L1
Nerium oleander	17	0.04	L2
Ochna serrulata	3	0.01	LR
Peltophorum pterocarpum	104	0.24	L1
Persea americana	52	0.12	L1
Phoenix roebelenii	48	0.11	L1
Plumeria species	754	1.72	L1
Polyalthia longifolia	2	0.00	L1
Pritchardia pacifica	201	0.46	L1
Pseudobombax ellipticum	11	0.03	L1
Pterocarpus indicus	57	0.13	L2
Ravenala madagascariensis	18	0.04	L2
Roystonea regia	260	0.59	L1
Samanea saman	1,376	3.14	L1
Schefflera actinophylla	144	0.33	L1
Sesbania grandiflora	20	0.05	L1
Swietenia mahogani	245	0.56	L1
Syagrus romanzoffiana	4	0.01	L1
Tabebuia aurea	1,309	2.99	L1
Tabebuia donnell-smithii	58	0.13	L1
Tabebuia heterophylla	3,020	6.89	L1
Tabebuia impetiginosa	2	0.00	L1
Tabebuia ochracea subsp. *neochrysantha*	673	1.54	L1
Tamarindus indica	42	0.10	L1
Terminalia catappa	24	0.05	L1

Species	No. of trees	% of population	Reference
Tipuana tipu	20	0.05	L1
Tournefortia argentea	3	0.01	L1
Veitchia merrillii	1,699	3.88	L1
Subtotal	25,987	59.3	
Undetermined			
Acoelorraphe wrightii	1	0.00	E
Agathis vitiensis	1	0.00	
Amherstia nobilis	1	0.00	
Annona reticulata	1	0.00	NN
Archontophoenix alexandrae	515	1.18	E
Averrhoa bilimbi	11	0.03	
Azadirachta indica	2	0.00	E
Bauhinia hookeri	123	0.28	
Bauhinia species	130	0.30	
Beaucarnea recurvata	13	0.03	
Bougainvillea species	44	0.10	
Butia capitata	3	0.01	NN
Calophyllum inophyllum	618	1.41	E
Calycophyllum candidissimum	11	0.03	NN
Carissa macrocarpa	1	0.00	NN
Caryota mitis	19	0.04	E
Chamaerops humilis	1	0.00	NN
Citrus sinensis	2	0.00	NN
Citrus species	13	0.03	NN
Clusia rosea	407	0.93	E; M1
Cocos nucifera	2,657	6.06	NN
Conocarpus erectus var. *argenteus*	1,162	2.65	L1; M1
Corypha utan	2	0.00	NN
Cotinus coggygria	4	0.01	NN
Cupressus sempervirens	249	0.57	NN
Cupressus species	45	0.10	NN
Dalbergia species	45	0.10	NN
Dypsis decaryi	64	0.15	NN
Erythrina species	330	0.75	
Eucalyptus citriodora	22	0.05	NN
Eucalyptus species	17	0.04	
Euphorbia tirucalli	3	0.01	NN
Ficus benjamina	309	0.71	E
Ficus macrophylla	15	0.03	E
Ficus species	27	0.06	
Ficus virens	24	0.05	
Filicium decipiens	1,775	4.05	E
Fraxinus uhdei	2	0.00	
Harpephyllum caffrum	168	0.38	NN
Hura crepitans	1	0.00	
Ilex paraguariensis	836	1.91	NN

Species	No. of trees	% of population	Reference
Koelreuteria elegans	367	0.84	E
Lagunaria patersonii	1	0.00	NN
Ligustrum japonicum	6	0.01	E
Livistona chinensis	7	0.02	E
Macadamia integrifolia	10	0.02	NN
Manilkara zapota	6	0.01	NN
Mimusops caffra	41	0.09	NN
Morus nigra	2	0.00	NN
Morus species	22	0.05	NN
Murraya paniculata	21	0.05	E
Musa species	12	0.03	NN
Noronhia emarginata	97	0.22	E
Ochrosia elliptica	5	0.01	NN
Orbignya cohune	1	0.00	NN
Palm species	132	0.30	
Pandanus tectorius	18	0.04	NN
Parmentiera cereifera	1	0.00	
Phoenix canariensis	1	0.00	NN
Phoenix dactylifera	34	0.08	NN
Phoenix species	8	0.02	
Pinus pinea	1	0.00	NN
Pinus species	13	0.03	
Pinus thunbergiana	8	0.02	NN
Pittosporum arborescens	9	0.02	
Platymiscium pinnatum	11	0.03	
Podocarpus neriifolius	96	0.22	
Podocarpus species	259	0.59	
Podocarpus usambarensis	2	0.00	NN
Prosopis pallida	26	0.06	NN
Salix matsudana	4	0.01	NN
Schefflera pueckleri	20	0.05	NN
Syagrus coronata	1	0.00	NN
Syzygium jambos	17	0.04	NN
Tabebuia bahamensis	6	0.01	NN
Tabebuia species	241	0.55	NN
Tabernaemontana pandacaqui	44	0.10	NN
Vitex parviflora	40	0.09	NN
Subtotal	11,264	25.7	
Total	43,817	100	

E: Evaluate (HPWRA 2007)
L1: Not currently recognized as invasive in Hawaii, and not likely to have major ecological or economic impacts on other Pacific Islands (HP-WRA 2007)
L2: Not currently recognized as invasive in Hawaii based on a track record of not becoming naturalized despite being widely planted in Hawaii for at least 40 years. = L(HAWAII) (HPWRA 2007)
H1: Likely to be invasive in Hawaii and on other Pacific Islands as determined by the HP- WRA screening process = H(HPWRA) (HPWRA 2007)
H2: Documented to cause significant ecological or economic harm in Hawaii, as determined from published information on the species' current impacts in Hawaii = H(HAWAII) (HPWRA 2007)
M1: Most invasive, http://www.state.hi.us/dlnr/dofaw/hortweeds/specieslist.htm (DNLR 2007)
Native: http://www.botany.hawaii.edu/faculty/carr/natives.htm

Appendix C—Replacement Values

Table C1—*Replacement value ($) for Honolulu's inventoried trees.*

Species	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of total
Monkeypod	8,866	170,319	2,132,656	2,424,668	2,828,561	2,143,367	1,342,048	1,237,283	12,287,767	16.9
Rainbow shower tree	417,010	2,147,588	3,716,002	757,658	102,677	-	-	-	7,140,935	9.8
West Indian mahogany	530	17,810	111,996	385,513	837,238	828,738	466,241	251,293	2,899,358	4.0
Pink tecoma	165,950	769,697	1,496,260	350,711	36,973	6,148	-	-	2,825,739	3.9
Giant crapemyrtle	250,393	813,805	1,574,488	154,980	13,506	-	-	-	2,807,172	3.9
Fern tree	248,165	1,044,778	1,346,217	28,090	-	-	-	-	2,667,251	3.7
Royal poinciana	23,781	253,205	1,371,474	665,856	138,820	62,533	16,075	-	2,531,744	3.5
Satinleaf	163,849	786,124	1,296,184	33,902	-	-	-	23,019	2,303,078	3.2
Ironwood	18,490	31,477	196,267	576,641	454,302	319,735	383,527	124,335	2,104,774	2.9
Coconut palm	63,091	702,405	1,232,574	8,375	-	-	-	-	2,006,446	2.8
False olive	180,080	735,967	880,482	104,344	-	-	-	-	1,900,873	2.6
Silver trumpet tree	183,597	1,031,699	635,080	16,467	-	-	-	-	1,866,843	2.6
Kamani	54,995	214,273	159,966	233,455	285,944	510,273	20,514	-	1,479,421	2.0
Pink and white shower	55,120	93,930	330,668	616,978	198,468	18,133	25,312	41,777	1,380,385	1.9
Silver buttonwood	249,479	404,769	460,820	157,988	88,095	-	-	-	1,361,152	1.9
Golden shower	25,305	312,315	777,517	155,902	29,365	-	-	-	1,300,404	1.8
Paperbark	24,846	236,351	568,201	310,343	73,304	46,220	-	-	1,259,266	1.7
Golden trumpet tree	82,986	420,609	606,339	107,033	13,506	-	-	-	1,230,474	1.7
Manila palm	910,204	53,528	9,159	1,128	796	-	-	-	974,817	1.3
Geiger tree	378,916	453,809	16,678	-	-	-	-	-	849,403	1.2
Coral tree species	7,515	39,964	371,995	310,231	60,018	31,267	16,075	-	837,063	1.2
Pink shower	12,630	100,155	511,988	154,183	17,214	-	-	-	796,169	1.1
Benjamin fig	17,679	48,541	149,362	109,184	231,944	93,248	-	28,145	678,104	0.9
Plumeria	191,537	369,516	50,587	-	-	-	-	-	611,640	0.8
Allspice	157,727	326,909	95,978	10,434	-	-	-	-	591,049	0.8
Yokewood	-	1,270	71,558	180,228	224,861	63,893	11,347	-	553,157	0.8
Goldenrain tree	24,438	312,898	169,982	14,045	-	-	-	-	521,364	0.7
Unidentified	84,929	123,440	158,634	74,943	50,444	12,067	8,213	-	512,670	0.7
Orchid tree 'purpurea'	22,743	228,154	219,361	37,486	-	-	-	-	507,744	0.7
Kou	108,162	253,286	128,959	14,045	-	-	-	-	504,452	0.7
Mamalis	45,760	230,801	199,778	8,597	-	-	-	-	484,936	0.7
African-tulip tree	16,665	38,512	133,420	149,403	54,420	32,278	46,264	-	470,963	0.6
Norfolk Island pine	14,932	122,915	132,986	149,168	50,053	-	-	-	470,054	0.6
Oriental arborvitae	296,983	144,202	12,835	-	-	-	-	-	454,021	0.6
Cinnamon	33,242	94,364	225,099	97,056	-	-	-	-	449,762	0.6
Paraguay-tea	133,290	262,712	40,810	4,775	-	-	-	-	441,588	0.6
Yellow poinciana	-	5,923	106,745	103,485	131,856	60,494	32,150	-	440,653	0.6
Hong Kong orchid tree	40,894	145,683	190,259	-	-	-	-	-	376,835	0.5
Alexandra palm	231,730	144,353	-	-	-	-	-	-	376,082	0.5
Kukui	51,973	129,888	108,221	58,602	19,386	-	-	-	368,069	0.5
Wiliwili	5,186	36,913	188,217	30,619	93,463	-	-	-	354,397	0.5
Autograph tree	121,204	159,524	19,825	-	-	-	-	-	300,553	0.4
Cuban royal palm	29,036	51,588	154,964	23,875	3,225	-	-	-	262,687	0.4
Areca palm	215,915	30,545	9,823	796	-	-	-	-	257,079	0.4
Fiddlewood	95,093	97,106	41,465	7,129	11,434	-	-	-	252,228	0.3
Italian cypress	52,893	124,143	59,997	12,065	-	-	-	-	249,098	0.3

Species	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of total
Trumpet tree	46,707	81,789	92,567	22,278	-	-	-	-	243,340	0.3
Sago palm	133,441	32,504	71,549	-	-	-	-	-	237,494	0.3
Partridgewood	2,143	21,224	158,037	47,128	5,885	-	-	-	234,417	0.3
Chinese banyan	1,553	4,860	33,244	13,732	4,361	15,383	8,800	133,916	215,848	0.3
Koa	47,775	67,281	59,748	24,700	13,506	-	-	-	213,010	0.3
Formosan koa	14,511	37,475	161,023	-	-	-	-	-	213,008	0.3
Narra	326	5,206	104,590	40,142	39,441	-	20,514	-	210,219	0.3
Banyan	-	2,401	2,203	10,321	27,695	40,988	24,200	84,436	192,244	0.3
Orchid tree	25,112	43,328	96,845	24,700	-	-	-	-	189,985	0.3
Orchid tree ‘hookeri’	9,954	93,398	73,540	-	-	-	-	-	176,892	0.2
Mango	2,978	7,768	23,323	31,092	20,217	34,840	20,641	28,145	169,005	0.2
Moreton Bay fig	-	-	-	3,625	11,770	17,420	60,499	70,363	163,678	0.2
Weeping bottlebrush	25,706	103,404	20,637	8,233	-	-	-	-	157,981	0.2
Looking-glass tree	79,078	76,938	-	-	-	-	-	-	156,016	0.2
Orchid tree, variegated	6,568	25,421	94,983	21,019	-	-	-	-	147,991	0.2
Kiawe	470	1,424	13,524	14,326	23,366	59,135	16,075	18,705	147,025	0.2
Octopus tree	9,134	40,622	66,585	19,150	4,154	3,791	-	-	143,436	0.2
Lignum-vitae	7,209	134,286	-	-	-	-	-	-	141,495	0.2
Podocarpus	41,874	54,458	41,979	-	-	-	-	-	138,311	0.2
Sea-grape	7,546	60,453	57,524	10,434	-	-	-	-	135,957	0.2
Swamp mahagony	274	2,357	39,947	44,879	33,602	12,757	-	-	133,817	0.2
Tulipwood	65,834	41,385	21,398	-	-	-	-	-	128,617	0.2
Indian coral tree	1,062	13,115	113,197	-	-	-	-	-	127,374	0.2
Sissoo	372	18,660	50,688	57,633	-	-	-	-	127,353	0.2
Jacaranda	1,279	16,902	84,431	8,146	-	11,555	-	-	122,313	0.2
Opiuma	506	2,401	17,918	36,252	11,770	14,858	8,541	14,073	106,320	0.1
Brown pine	11,963	50,492	41,223	-	-	-	-	-	103,679	0.1
Palm	37,039	37,715	14,542	1,151	-	-	-	-	90,447	0.1
Tree wisteria	373	2,018	10,062	38,765	15,577	23,110	-	-	89,905	0.1
Fiji fan palm	38,641	45,993	3,442	-	-	-	-	-	88,077	0.1
Cook-pine	3,258	16,613	46,308	19,857	-	-	-	-	86,036	0.1
False kamani	2,342	13,812	17,114	-	-	20,098	-	32,611	85,976	0.1
Molave	324	3,202	65,631	3,625	-	-	-	-	72,782	0.1
Madagascar-olive	26,623	43,460	-	-	-	-	-	-	70,083	0.1
Gold tree	6,386	44,236	15,856	-	-	-	-	-	66,477	0.1
Kelakid	461	22,891	26,325	16,467	-	-	-	-	66,144	0.1
Red bottlebrush	9,026	16,593	40,268	-	-	-	-	-	65,887	0.1
Red milkwood	1,558	11,212	35,339	14,259	-	-	-	-	62,368	0.1
Milo	5,627	17,405	31,093	4,068	4,036	-	-	-	62,229	0.1
Pride of Bolivia	231	9,852	50,587	-	-	-	-	-	60,669	0.1
Kaffir-plum	58,236	2,366	-	-	-	-	-	-	60,602	0.1
Christmas berry	1,933	17,970	26,487	13,596	-	-	-	-	59,985	0.1
Silky-oak	-	-	24,225	23,065	-	10,240	-	-	57,530	0.1
Avocado	12,160	18,881	16,490	8,658	-	-	-	-	56,189	0.1
Ara	129	4,331	16,465	13,435	11,770	8,710	-	-	54,840	0.1
Siris tree	370	-	4,291	19,101	7,789	-	16,075	-	47,626	0.1
Triangle palm	16,665	17,025	13,540	-	-	-	-	-	47,229	0.1
Bottle palm	12,308	11,670	19,307	2,582	-	-	-	-	45,867	0.1
Crapemyrtle	4,311	7,727	12,835	16,467	-	-	-	-	41,340	0.1

Species	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of total
Mallet flower	-	7,062	32,701	-	-	-	-	-	39,763	0.1
Chachimbo	-	2,801	36,090	-	-	-	-	-	38,891	0.1
Spindle palm	13,183	21,075	4,303	-	-	-	-	-	38,561	0.1
Hau	5,083	3,169	2,515	4,775	22,358	-	-	-	37,901	0.1
Mexican washingtonia	2,628	17,711	17,423	-	-	-	-	-	37,762	0.1
Indian coral tree, oriental	7,168	1,009	14,353	14,326	-	-	-	-	36,856	0.1
Magnolia	14,210	18,255	4,278	-	-	-	-	-	36,743	0.1
Be-still tree	16,397	12,213	7,546	-	-	-	-	-	36,157	0.0
Busbusilak	7,616	3,296	1,930	2,559	5,885	12,296	-	-	33,582	0.0
Rose-apple	420	2,726	13,011	-	11,434	5,935	-	-	33,526	0.0
Indian banyan	408	-	-	3,625	-	-	-	28,145	32,178	0.0
Strawberry guava	11,731	5,119	3,020	11,624	-	-	-	-	31,494	0.0
Earpod	-	1,457	12,286	-	-	-	-	17,415	31,158	0.0
Macarthur palm	27,819	1,702	-	-	-	-	-	-	29,521	0.0
Papaya	24,909	4,154	-	-	-	-	-	-	29,063	0.0
Date palm	-	20,061	6,786	1,963	-	-	-	-	28,811	0.0
Bitter bark	9,384	7,205	10,062	-	-	-	-	-	26,651	0.0
Mindanao gum	1,916	5,452	12,162	6,081	-	-	-	-	25,611	0.0
Guava	15,352	9,852	-	-	-	-	-	-	25,203	0.0
Lemon-scented gum	1,272	11,632	7,103	4,775	-	-	-	-	24,782	0.0
Hollywood juniper	4,374	11,494	8,557	-	-	-	-	-	24,424	0.0
Carrotwood	2,412	21,788	-	-	-	-	-	-	24,199	0.0
Pepper tree	-	-	3,327	8,136	4,036	7,319	-	-	22,818	0.0
Dwarf date palm	9,500	11,670	-	-	-	-	-	-	21,170	0.0
Coral tree	1,404	12,653	6,141	-	-	-	-	-	20,198	0.0
Buttercup tree	-	-	-	-	-	20,098	-	-	20,098	0.0
Mulberry	1,748	10,670	2,515	4,775	-	-	-	-	19,709	0.0
Olive	1,334	11,759	5,350	-	-	-	-	-	18,442	0.0
Pride-of-India	294	9,269	2,264	6,032	-	-	-	-	17,860	0.0
Cucumber tree	2,995	14,706	-	-	-	-	-	-	17,701	0.0
Cypress	15,401	1,642	-	-	-	-	-	-	17,043	0.0
Horseradish tree	1,373	3,991	7,504	3,565	-	-	-	-	16,433	0.0
Soursop	11,749	4,443	-	-	-	-	-	-	16,192	0.0
Sugar apple	11,283	4,443	-	-	-	-	-	-	15,726	0.0
Traveller's palm	1,660	6,733	5,791	-	-	-	-	-	14,183	0.0
Bo tree	-	-	-	-	-	-	-	14,073	14,073	0.0
Shaving brush tree	185	9,080	-	4,775	-	-	-	-	14,040	0.0
Chinese juniper	-	-	-	-	13,506	-	-	-	13,506	0.0
Macadamia nut	2,130	2,801	8,557	-	-	-	-	-	13,488	0.0
Bouganvillea	10,794	2,136	-	-	-	-	-	-	12,930	0.0
Dracaena palm	5,193	7,596	-	-	-	-	-	-	12,789	0.0
Bangalow palm	2,095	10,215	-	-	-	-	-	-	12,310	0.0
Oleander	1,729	7,893	2,515	-	-	-	-	-	12,138	0.0
Mock orange	3,958	5,626	2,515	-	-	-	-	-	12,100	0.0
Hala	1,838	6,162	-	3,565	-	-	-	-	11,564	0.0
Grapefruit	1,445	10,045	-	-	-	-	-	-	11,490	0.0
Lemonwood	1,122	9,272	-	-	-	-	-	-	10,394	0.0
Stiff bottlebrush	1,993	8,113	-	-	-	-	-	-	10,107	0.0
Banana	2,328	4,036	1,776	-	-	-	-	-	8,139	0.0

Species	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of total
Japanese black pine	824	7,166	-	-	-	-	-	-	7,990	0.0
Fiddle-leaf fig	-	2,366	1,951	3,565	-	-	-	-	7,881	0.0
Ulu	-	2,136	5,031	-	-	-	-	-	7,167	0.0
Sesban	3,296	3,861	-	-	-	-	-	-	7,156	0.0
Cemetery tree	-	1,159	-	5,812	-	-	-	-	6,971	0.0
Fishtail palm	5,449	1,167	-	-	-	-	-	-	6,616	0.0
Pummelo	530	1,642	4,278	-	-	-	-	-	6,450	0.0
Litchi	1,564	4,773	-	-	-	-	-	-	6,337	0.0
Moluccan albizia	182	-	-	-	-	6,148	-	-	6,331	0.0
New Caledonia tree	740	-	-	-	5,498	-	-	-	6,238	0.0
Jatropha	5,074	1,009	-	-	-	-	-	-	6,083	0.0
Date palm species	1,077	4,815	-	-	-	-	-	-	5,892	0.0
Tropical ash	-	-	2,515	3,371	-	-	-	-	5,886	0.0
Citrus	4,726	1,159	-	-	-	-	-	-	5,885	0.0
Noni	1,931	3,857	-	-	-	-	-	-	5,789	0.0
Lemi	4,067	1,642	-	-	-	-	-	-	5,709	0.0
Scrambled egg tree	5,657	-	-	-	-	-	-	-	5,657	0.0
Chinese fan palm	1,029	3,405	1,128	-	-	-	-	-	5,562	0.0
Colville’s glory	-	-	5,350	-	-	-	-	-	5,350	0.0
Eucalyptus	4,624	381	-	-	-	-	-	-	5,005	0.0
White dwarf tabebuia	747	4,036	-	-	-	-	-	-	4,782	0.0
Pine	4,340	-	-	-	-	-	-	-	4,340	0.0
Mandarin orange	1,031	3,284	-	-	-	-	-	-	4,315	0.0
Pittosporum	2,179	1,749	-	-	-	-	-	-	3,928	0.0
Ponytail	3,716	-	-	-	-	-	-	-	3,716	0.0
Calabash tree	-	-	3,020	-	-	-	-	-	3,020	0.0
Floss-silk tree	152	712	-	2,079	-	-	-	-	2,943	0.0
Indian rubber tree	817	-	1,930	-	-	-	-	-	2,748	0.0
Jack fruit	1,000	1,642	-	-	-	-	-	-	2,642	0.0
Tree heliotrope	420	-	2,180	-	-	-	-	-	2,600	0.0
Queen palm	1,739	695	-	-	-	-	-	-	2,434	0.0
Jelly palm	-	535	-	623	1,072	-	-	-	2,230	0.0
Japanese privet	1,059	-	1,095	-	-	-	-	-	2,154	0.0
Gardenia	2,151	-	-	-	-	-	-	-	2,151	0.0
Black mulberry	-	2,018	-	-	-	-	-	-	2,018	0.0
Kona orange	374	1,642	-	-	-	-	-	-	2,016	0.0
Pencil tree	263	1,721	-	-	-	-	-	-	1,985	0.0
Camphor tree	1,970	-	-	-	-	-	-	-	1,970	0.0
Mickey Mouse plant	558	1,009	-	-	-	-	-	-	1,567	0.0
Surinam-cherry	1,478	-	-	-	-	-	-	-	1,478	0.0
Koa haole	1,379	-	-	-	-	-	-	-	1,379	0.0
Bay-rum tree	1,209	-	-	-	-	-	-	-	1,209	0.0
Weeping willow	1,165	-	-	-	-	-	-	-	1,165	0.0
Lipstick plant	1,127	-	-	-	-	-	-	-	1,127	0.0
Cohune palm	-	-	-	1,117	-	-	-	-	1,117	0.0
Sapodilla	1,088	-	-	-	-	-	-	-	1,088	0.0
East African yellow wood	1,059	-	-	-	-	-	-	-	1,059	0.0
Natal plum	-	1,009	-	-	-	-	-	-	1,009	0.0
Licury palm	-	-	969	-	-	-	-	-	969	0.0

Species	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of total
Canary Island date palm	-	-	866	-	-	-	-	-	866	0.0
Buri palm	865	-	-	-	-	-	-	-	865	0.0
Primrose tree	-	-	840	-	-	-	-	-	840	0.0
Smoketree	819	-	-	-	-	-	-	-	819	0.0
Common fig	-	800	-	-	-	-	-	-	800	0.0
Pittosporum species	-	617	-	-	-	-	-	-	617	0.0
Silver saw palmetto	-	-	-	-	-	607	-	-	607	0.0
Ohi'a lehua	541	-	-	-	-	-	-	-	541	0.0
Custard apple	530	-	-	-	-	-	-	-	530	0.0
Amapa rosa	515	-	-	-	-	-	-	-	515	0.0
Neem tree	506	-	-	-	-	-	-	-	506	0.0
Nandu	-	-	503	-	-	-	-	-	503	0.0
Candle tree	-	439	-	-	-	-	-	-	439	0.0
Sandbox tree	436	-	-	-	-	-	-	-	436	0.0
Pride of Burma	420	-	-	-	-	-	-	-	420	0.0
Pua kenikeni	374	-	-	-	-	-	-	-	374	0.0
Loquat	287	-	-	-	-	-	-	-	287	0.0
European fan palm	247	-	-	-	-	-	-	-	247	0.0
Hibiscus	152	-	-	-	-	-	-	-	152	0.0
Umbrella pine	128	-	-	-	-	-	-	-	128	0.0
Citywide total	6,636,627	16,148,917	24,776,830	9,370,413	6,348,601	4,553,684	2,543,110	2,147,733	72,525,916	100.0

Appendix D—Methodology and Procedures

This analysis combines results of a citywide inventory with benefit–cost modeling data to produce four types of information:

1. Resource structure (species composition, diversity, age distribution, condition, etc.)
2. Resource function (magnitude of environmental and aesthetic benefits)
3. Resource value (dollar value of benefits realized)
4. Resource management needs (sustainability, pruning, planting, and conflict mitigation)

This Appendix describes municipal tree sampling, tree growth modeling, and the model inputs and calculations used to derive the aforementioned outputs.

Growth Modeling

A stratified random sample of 901 park trees, drawn from Honolulu's municipal tree database, was inventoried to establish relations between tree age, size, leaf area and biomass; subsequently, estimates for determining the magnitude of annual benefits in relation to predicted tree size were derived. The sample was composed of 21 of the most abundant species; from these data, growth of all trees was inferred. The species were as follows:

- Hong Kong orchid tree (*Bauhinia* x *blakeana*)
- Ironwood (*Casuarina equisetifolia*)
- Kamani (*Calophyllum inophyllum*)
- Rainbow shower tree (*Cassia* x *nealiae*)
- Fiddlewood (*Citharexylum spinosum*)
- Silver buttonwood (*Conocarpus erectus* var. *argenteus*)
- Kou (*Cordia subcordata*)
- Royal poinciana (*Delonix regia*)
- False olive (*Elaeodendron orientale*)
- Benjamin fig (*Ficus benjamina*)
- Fern tree (*Filicium decipiens*)
- Paraguay-tea (*Ilex paraguariensis*)
- Giant crapemyrtle (*Lagerstroemia speciosa*)
- Paperbark (*Melaleuca quinquenervia*)
- Monkeypod (*Samanea saman*)
- West Indian mahogany (*Swietenia mahogani*)
- Silver trumpet tree (*Tabebuia aurea*)
- Golden trumpet tree (*Tabebuia ochracea* subsp. *neochrysantha*)
- Pink tecoma (*Tabebuia heterophylla*)
- Coconut palm (*Cocos nucifera*)
- Date palm (*Phoenix dactylifera*)
- Manila palm (*Veitchia merrillii*)

To obtain information spanning the life cycle of predominant tree species, the inventory was stratified into nine DBH classes:

- 0–2.9 in (0–7.6 cm)
- 3–5.9 in (7.6–15.2 cm)
- 6–11.9 in (15.2–30.5 cm
- 12–17.9 in (30.5–45.7 cm)
- 18–23.9 in (45.7–61.0 cm)
- 24–29.9 in (61.0–76.2 cm)
- 30–35.9 in (76.2–91.4 cm)
- 36–41.9 in (91.4–106.7 cm)
- >42 in (>106.7 cm)

Thirty-five to sixty randomly selected trees of each species were selected to survey, along with an equal number of alternative trees. Tree measurements included DBH (to nearest 0.1 cm by sonar measuring device), tree crown and crown base (to nearest 0.5 m by altimeter), crown diameter in two directions (parallel and perpendicular to nearest street to nearest 0.5 m by sonar measuring device), tree condition and location. Replacement trees were sampled when trees from the original sample population could not be located. Tree age was determined by municipal tree managers. Fieldwork was conducted in September 2005.

Crown volume and leaf area were estimated from computer processing of tree crown images obtained using a digital camera. The method has shown greater accuracy than other techniques (±25% of actual leaf area) in estimating crown volume and leaf area of open-grown trees (Peper and McPherson 2003).

Linear and non-linear regression was used to fit predictive models—with DBH as a function of age—for each of the 21 sampled species. Predictions of leaf surface area (LSA), crown diameter, and height metrics were modeled as a function of DBH using best-fit models (Peper et al. 2001).

Replacement Value

The monetary worth, or value, of a tree is based on people's perception of it (Cullen 2000). There are several approaches that arborists use to develop a fair and reasonable perception of value (CTLA 1992, Watson 2002). The cost approach is widely used today and assumes that the cost of production equals value (Cullen 2002).

The trunk formula method (CTLA 1992), also called depreciated replacement cost, is a commonly used approach for estimating tree value in terms of cost. It assumes that the benefits inherent in a tree are reproduced by replacing the tree, and therefore, replacement cost is an indication of value. Replacement cost is depreciated to reflect differences in the benefits that would flow from an "idealized" replacement compared to the imperfect appraised tree.

We regard the terms "replacement value" and "replacement cost" as synonymous indicators of the urban forest's value. Replacement value is indicated by the cost of replacing existing trees with trees of similar size, species, and condition if all were destroyed, for example, by a catastrophic storm. Replacement cost should be distinguished from the value of annual benefits produced by the urban forest. The latter is a "snapshot" of benefits during one year, while the former accounts for the long-term investment in trees now reflected in their number, stature, placement, and condition. Hence, the replacement value of a street tree population is many times greater than the value of the annual benefits it produces.

The trunk formula method uses tree size, species, condition, and location factors to determine tree replacement value. Tree size is measured as trunk area (TA, cross-sectional area of the trunk based on DBH), while the other factors are assessed subjectively relative to a "high-quality" specimen and expressed as percentages. The equation is

Replacement value = Basic value × Condition% × Location%

where

Basic value = Replacement cost + (Basic price × [TAA−TAR] × Species%)

Condition% = Rating of structural integrity and health; a higher percentage indicates better condition (CTLA 1992)

Location% = Rating of the site itself (relative market value), contribution of the tree in terms of its aesthetic and functional attributes, and placement, which reflects the effectiveness of realizing benefits; location is the sum of site, contribution, and placement divided by three (CTLA 1992). A higher percentage indicates better location.

Replacement cost = Sum of the cost of the replacement tree (of size TAR) and its installation

Basic price = Cost of the largest available transplantable tree divided by TAR ($/in^2)

TAA = Trunk area of appraised tree (in^2) or height of clear trunk (linear ft) for palms

TAR = Trunk area of replacement tree (in^2) or height of clear trunk (linear ft) for palms

Species% = Rating of the species's longevity, maintenance requirements, and adaptability to the local growing environment (CTLA 1992)

In this study, data from the Western Chapter ISA Regional Supplement for the North Coast of California are used to calculate replacement value (WC-ISA 2004). Species rating percentages are the midpoint for the ranges reported for the Hawaii Subregion. Street tree condition ratings are based on the inventory (or set at 70% when no data are available) and location ratings are arbitrarily set at 70%, indicative of a tree located along a typical street. TA_R , by nursery group, is based on trunk diameters for up to a 200 gallon or 1 cubic yard root mass as shown below:

Nursery group no.	Average trunk diameter (in)	Cost per in^2
1	3.0	128
2	4.5	56
3	6	32
4	7	24

TA_A is calculated using the midpoint for each DBH class. The basic price is also based on nursery group for each species.

There were no palm data for the region, so basic prices ($/linear ft of clear trunk) and replacement costs ($/palm), which vary by species, were obtained from interviews with Kevin Eckert [WC-ISA Hawaii Subcommittee Chairman for the Western Chapter ISA Regional Supplement for the North Coast of California (WC-ISA 2004)] and Lelan Nishek, Kauai Nursery & Landscaping, Inc. TA_R is assumed to be 15 linear ft; TA_A is calculated as the midpoint for each palm height class.

Replacement values are calculated using the trunk formula equation for each species by DBH class, then summed across DBH classes and species to derive total replacement value for the population.

Identifying and Calculating Benefits

Annual benefits for Honolulu's municipal trees were estimated for the fiscal year 2005–2006. Growth rate modeling information was used to perform computer-simulated growth of the existing tree population for 1 year and account for the associated annual benefits. This "snapshot" analysis assumed that no trees were added to, or removed from, the existing population during the year. (Calculations of CO_2 released due to decomposition of wood from removed trees did consider average annual mortality.) This approach directly connects benefits with tree-size variables such as DBH and LSA. Many functional benefits of trees are related to processes that involve interactions between leaves and the atmosphere (e.g., interception, transpiration, photosynthesis); therefore, benefits increase as tree canopy cover and leaf surface area increase.

For each of the modeled benefits, an annual resource unit was determined on a per-tree basis. Resource units are measured as MWh of electricity saved per tree; lbs of atmospheric CO_2 reduced per tree; lbs of NO_2, PM_{10}, and VOCs reduced per tree; cubic feet of stormwater runoff reduced per tree; and square feet of leaf area added per tree to increase property values.

Prices were assigned to each resource unit (e.g., heating/cooling energy savings, air-pollution absorption, stormwater runoff reduction) using economic indicators of society's willingness to pay for the environmental benefits trees provide. Estimates of benefits are initial approximations as some benefits are difficult to quantify (e.g., impacts on psychological health, crime, and violence). In addition, limited knowledge about the physical processes at work and their interactions makes estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Therefore, this method of quantification provides first-order approximations. It is meant to be a general accounting of the benefits produced by urban trees—an accounting with an accepted degree of uncertainty that can, nonetheless, provide a science-based platform for decision-making.

Energy Savings

Buildings and paving, along with little tree canopy cover and soil cover, increase the ambient temperatures within a city. Research shows that even in temperate climate zones temperatures in urban centers are steadily increasing by approximately 0.5°F per decade. Winter benefits of this warming do not compensate for the detrimental effects of increased summertime temperatures. Because the electricity demand of cities increases about 1–2% per 1°F increase in temperature, approximately 3–8% of the current electric demand for cooling is used to compensate for this urban heat island effect (Akbari et al. 1992).

Warmer temperatures in cities have other implications. Increases in CO_2 emissions from fossil-fuel power plants, increased municipal water demand, unhealthy ozone levels, and human discomfort and disease are all symptoms associated with urban heat islands. In Honolulu, there are opportunities to ameliorate the problems associated with hardscape through strategic tree planting and stewardship of existing trees thereby creating street and park landscapes that reduce stormwater runoff, conserve energy and water, sequester CO_2, attract wildlife, and provide other aesthetic, social, and economic benefits.

Calculating Electricity Benefits

Calculations of annual building energy use per residential unit (unit energy consumption [UEC]) were based on computer simulations that incorporated building, climate, and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs due to the effects of trees (ΔUECs) were calculated on a per-tree basis by comparing results before and after adding trees. Building characteristics (e.g., cooling equipment saturations, floor area, number of stories, insulation, window area, etc.) are differentiated by a building's vintage, or age of construction: pre-1950, 1950–1980, and post-1980. For example, all houses from 1950–1980 vintage are assumed to have the same area, and other construction characteristics. Shading effects for each of the 21 tree species were simulated at three tree-to-building distances, for eight orientations and for nine tree sizes.

The shading coefficients of the trees in leaf (gaps in the crown as a percentage of total crown silhouette) were estimated using a photographic method that has been shown to produce good estimates (Wilkinson 1991). Crown areas were obtained using the method of Peper and McPherson (2003) from digital photographs of trees from which background features were digitally removed. Values for tree species that were not sampled, and leaf-off values for use in calculating winter shade, were based on published values where available (McPherson 1984; Hammond et al. 1980). Where published values were not available, visual densities were assigned based on taxonomic considerations (trees of the same genus were assigned the same value) or observed similarity to known species. Foliation periods for deciduous trees were determined based on consultation with forestry supervisors and a horticulturist from the Honolulu Botanical Gardens (Oka 2006; Sand 2006).

Average energy savings per tree were calculated as a function of distance and direction using tree location distribution data specific to Honolulu (i.e., frequency of trees located at different distances from buildings [setbacks] and tree orientation with respect to buildings). Setbacks were assigned to four distance classes: 0–20 ft, 20–40 ft, 40–60 ft and >60 ft. It was assumed that street trees within 60 ft of buildings provided direct shade on walls and windows. Savings per tree at each location were multiplied by tree distribution to determine location-weighted savings per tree for each species and DBH class, independent of location. Location-weighted savings per tree were multiplied by the number of trees of each species and DBH class and then summed to find total savings for the city. Tree locations were based on the stratified random sample conducted in September 2005.

Land use (single-family residential, multifamily residential, commercial/industrial, other) for right-of-way trees was based on the same tree sample. A constant tree distribution was used for all land uses.

Three prototype buildings were used in the simulations to represent pre-1950, 1950–1980, and post-1980 construction practices for Honolulu (Ritschard et al. 1992). Building footprints were modeled as square, which was found to reflect average impacts for a large number of buildings (Simpson 2002). Buildings were simulated with 1.5-ft overhangs. Blinds had a visual density of 37%, and were assumed to be closed when the air conditioner was operating. Thermostat settings were 78°F for cooling. Unit energy consumptions were adjusted to account for equipment saturations (percentage of structures with different types of cooling equipment such as central air conditioners, room air conditioners, and evaporative coolers) (*Table D1*).

Weather data for a typical meteorological year (TMY2) from Honolulu were used (Renewable Resource Data Center 1995). Dollar values for energy savings were based on electricity and natural gas prices of \$0.1767/kWh and \$2.99/therm, respectively (Hawaiian Electric Company 2007; The Gas Company).

Single-Family Residence Adjustments

Unit energy consumptions for simulated single-family residences were adjusted for type and saturation of cooling equipment, and for various factors (F) that modify the effects of shade and climate on cooling loads:

$$\Delta UECx = \Delta UEC^{sh}_{SFD} \times F^{sh} + \Delta UEC^{cl}_{SFD} \times F^{cl} \qquad \textit{Equation 1}$$

where

$$F^{sh} = F_{equipment} \times APSF \times F_{adjacent\ shade} \times F_{multiple\ tree}$$

$$F^{cl} = F_{equipment} \times PCF$$

$$F_{equipment} = Sat_{CAC} + Sat_{window} \times 0.25 + Sat_{evap} \times 0.33.$$

Changes in energy use for higher density residential and commercial structures were calculated from single-family residential results adjusted by average potential shade factors (APSF) and potential climate factors (PCF); values were set to 1.0 for single-family residential buildings.

Total change in energy use for a particular land use was found by multiplying the change in UEC per tree by the number of trees (N):

$$\text{Total change} = N \times \Delta UEC_x \qquad \textit{Equation 2}$$

Subscript *x* refers to residential structures with 1, 2–4 or ≥5 units, SFD to simulated single-family detached structures, sh to shade, and cl to climate effects.

Estimated shade savings for all residential structures were adjusted to account for shading of neighboring buildings and for overlapping shade from trees adjacent to one another. Homes adjacent to those with shade trees may benefit from the trees on the neighboring properties. For example, 23% of the trees planted for the Sacramento Shade program shaded neighboring homes, resulting in an additional estimated energy savings equal to 15% of that found for program participants; this value was used here ($F_{adjacent\ shade} = 1.15$). In addition, shade from multiple trees may overlap, resulting in less building shade from an added tree than would result if there were no existing trees. Simpson (2002) estimated that the fractional reductions in average cooling and heating energy use were approximately 6% and 5% percent per tree, respectively, for each tree added after the first. Simpson (1998) also found an average of 2.5–3.4 existing trees per residence in Sacramento. A multiple tree reduction factor of 85% was used here, equivalent to approximately three existing trees per residence.

***Table D1**—Saturation adjustments for cooling (%)/*

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Instit./ Trans-porta-tion
	pre-1950	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**Small**	**Large**	
Cooling equipment factors																		
Central air/ heat pump	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Evaporative cooler	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Wall/window unit	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
None	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling saturations																		
Central air/ heat pump	14	63	76	14	63	76	14	63	76	14	63	76	14	63	76	86	86	86
Evaporative cooler	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wall/window unit	59	23	5	59	23	5	59	23	5	59	23	5	59	23	5	9	9	9
None	27	14	19	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
Adjusted cooling saturation	28	69	77	28	69	77	28	69	77	28	69	77	28	69	77	88	88	88

In addition to localized shade effects, which were assumed to accrue only to street trees within 18–60 ft of buildings, lowered air temperatures and wind speeds due to neighborhood tree cover (referred to as climate effects) produce a net decrease in demand for cooling. Reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances. To estimate climate effects on energy use, air-temperature and wind-speed reductions were estimated as a function of neighborhood canopy cover from published values following McPherson and Simpson (1999), then used as input for the building energy-use simulations described earlier. Peak summer air temperatures were assumed to be reduced by 0.2°F for each percentage increase in canopy cover. Wind-speed reductions were based on the change in total tree plus building canopy cover resulting from the addition of the particular tree being simulated (Heisler 1990). A lot size of 10,000 ft^2 was assumed.

Cooling effects were reduced based on the type and saturation of air conditioning (*Table D2*) equipment by vintage. Equipment factors of 33 and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{equipment}$). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning (*Table D2*).

Multi-Family Residence Analysis

Unit energy consumptions (UECs) from single-family residential UECs were adjusted for multi-family residences (MFRs) to account for reduced shade resulting from common walls and multi-story construction. To do this, potential shade factors (PSFs) were calculated as ratios of exposed wall or roof (ceiling) surface area to total surface area, where total surface area includes common walls and ceilings between attached units in addition to exposed surfaces (Simpson 1998). A PSF of 1 indicates that all exterior walls and roofs are exposed and could be shaded by a tree, while a PSF of 0 indicates that no shading is possible (e.g., the common wall between duplex units). Potential shade factors were estimated separately for walls and roofs for both single- and multi-story structures. Average potential shade factors were 0.74 for multi-family residences of 2–4 units and 0.41 for ≥5 units.

Unit energy consumptions were also adjusted to account for the reduced sensitivity of multi-family buildings with common walls to outdoor temperature changes. Since estimates for these PCFs were unavailable for multi-family structures, a multi-family PCF value of 0.80 was selected (less than single-family detached PCF of 1.0 and greater than small commercial PCF of 0.40; see next section).

Commercial and Other Buildings

Reductions in unit energy consumptions for commercial/industrial (C/I) and industrial/transportation (I/T) land uses due to the presence of trees were determined in a manner similar to that used for multi-family land uses. Potential shade factors of 0.40 were assumed for small C/I, and 0.0 for large C/I. No energy impacts were ascribed to large C/I structures since they are expected to have surface-to-volume ratios an order of magnitude larger than smaller buildings and less extensive window area. Average potential shade factors for I/T structures were estimated to lie between these extremes; a value of 0.15 was used here. However, data relating I/T land use to building-space conditioning were not readily available, so no energy impacts were ascribed to I/T structures. A multiple-tree reduction factor of 0.85 was used, and no benefit was assigned for shading of buildings on adjacent lots.

Potential climate-effect factors of 0.40, 0.25 and 0.20 were used for small C/I, large C/I, and I/T, respectively. These values are based on estimates by Akbari (1992) and others who observed that commercial buildings are less sensitive to outdoor temperatures than houses.

The beneficial effects of shade on UECs tend to in-

Table D2*—Building vintage distribution and combined vintage/saturation factors for air conditioning.*

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Institutional/ Transportation
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
Vintage distribution by building type	12.9	51.3	35.8	11.3	48.1	40.6	12.9	51.3	35.8	12.6	54.1	33.4	4.1	63.3	32.6	100	100	100
Tree distribution by vintage and building type	11.6	46.0	32.1	0.0	0.1	0.1	1.3	5.2	3.6	2.4	10.4	6.4	3.3	51.1	26.3	63.0	37.0	100
Combined vintage, equipment saturation factors for cooling																		
Cooling factor: shade	3.21	31.06	24.25	0.01	0.10	0.09	0.32	3.06	2.39	0.50	5.21	3.61	0.38	14.13	8.16	19.4	5.7	0.0
Cooling factor: climate	3.28	31.77	24.80	0.01	0.09	0.09	0.30	2.88	2.25	0.31	3.24	2.24	0.43	16.23	9.37	17.4	34.1	0.0

crease with conditioned floor area (CFA) for typical residential structures. As building surface area increases so does the area shaded. This occurs up to a certain point because the projected crown area of a mature tree (approximately 700–3,500 ft^2) is often larger than the building surface areas being shaded. A point is reached, however, at which no additional area is shaded as surface area increases. At this point, ∆UECs will tend to level off as CFA increases. Since information on the precise relationships between change in UEC, CFA, and tree size is not available, it was conservatively assumed that ∆UECs in *Equation 1* did not change for C/I and I/T land uses.

Atmospheric Carbon Dioxide Reduction

Sequestration (the net rate of CO_2 storage in above- and below-ground biomass over the course of one growing season) is calculated for each species using the tree-growth equations for DBH and height, described above, to calculate either tree volume or biomass. Equations from Pillsbury et al. (1998) are used when calculating volume. Fresh weight (kg/m^3) and specific gravity ratios from Alden (1995, 1997) are then applied to convert volume to biomass. When volumetric equations for urban trees are unavailable, biomass equations derived from data collected in rural forests are applied (Tritton and Hornbeck 1982; Ter-Mikaelian and Korzukhin 1997).

Carbon dioxide released through decomposition of dead woody biomass varies with characteristics of the wood itself, the fate of the wood (e.g., amount left standing, chipped, or burned), and local soil and climatic conditions. Recycling of urban waste is now prevalent, and we assume here that most material is chipped and applied as landscape mulch. Calculations were conservative because they assumed that dead trees are removed and mulched in the year that death occurs, and that 80% of their stored carbon is released to the atmosphere as CO_2 in the same year. Total annual decomposition is based on the number of trees in each species and age class that die in a given year and their biomass. Tree survival rate is the principal factor influencing decomposition. Tree mortality for Honolulu was 1.0% per year for the first five years after planting for street trees and 0.4% every year thereafter (Oka 2006). Finally, CO_2 released during tree maintenance was estimated to be 0.297 lb CO_2 per inch DBH based on annual fuel consumption of gasoline (~780 gal) and diesel fuel (~4,160 gal) (Koike 2006).

Calculating Avoided CO_2 Emissions

Reducing building energy use reduces emissions of CO_2. Emissions were calculated as the product of energy use and CO_2 emission factors for electricity. The fuel mix for electrical generation include mainly oil (99.7%) (U.S. EPA 2003).

Emissions factors for electricity (lb/MWh) are given in *Table D3*. The monetary value of avoided CO_2 was $6.68/ton based on the average value in Pearce (2003).

Table D3*—Emissions factors and monetary implied values for CO_2 and criteria air pollutants.*

	Emission factor (lb/MWh)[a]	Implied value[b] ($/lb)
CO_2	1,849	0.00334
NO_2	5.912	1.47
SO_2	6.740	1.52
PM_{10}	0.997	1.34
VOCs	0.997	0.60

[a]USEPA 1998, 2003, except Ottinger et al. 1990 for VOCs
[b]CO_2 from Pearce (2003), values for all other pollutants are based on methods of Wang and Santini (1995) using emissions concentrations from U.S. EPA (2006) and population estimates from the U.S. Census Bureau (2006)

Improving Air Quality

Calculating Avoided Emissions

Reductions in building energy use also result in reduced emissions of criteria air pollutants (those for which a national standard has been set by the EPA) from power plants. This analysis considered 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}). Changes in average annual emissions and their monetary values were calculated in the same way as for CO_2, again using utility specific emission factors for electricity (U.S. EPA 2003). The prices of emissions savings were derived from models that calculate the marginal cost of controlling different pollutants to meet air quality standards (Wang and Santini 1995). Emissions concentrations were obtained from U.S. EPA (2003, *Table D3*), and population estimates from the U.S. Census Bureau (2006).

Calculating Deposition and Interception

Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of the deposition velocity $V_d = 1/(R_a+R_b+R_c)$, pollutant concentration (C), canopy projection (CP) area, and time step. Hourly deposition velocities for each pollutant were calculated using estimates for the resistances R_a, R_b, and R_c estimated for each hour over a year using formulations described by Scott et al. (1998). Hourly concentrations for NO_2, SO_2, O_3 and PM_{10} for Honolulu were obtained from the Environmental Protection Agency (U.S. EPA 2006). Hourly meteorological data (i.e., air temperature, windspeed, with the exception of solar radiation) were obtained from the National Climate Data Center (NCDC 2006). Solar radiation data were obtained from the Coconut Island Weather Station (Naughton 2006) . The year 2005 was chosen because maximum hourly average ozone and maximum 24-hour average PM_{10} concentrations most closely approximated the average value of those maxima during the last 5-year period.

Deposition was determined for deciduous species only when trees were in-leaf. A 50% re-suspension rate was applied to PM_{10} deposition. Methods described in the section "Calculating Avoided Emissions" were used to value emissions reductions; NO_2 prices were used for ozone since ozone control measures typically aim at reducing NO_2.

Calculating BVOC Emissions

Emissions of biogenic volatile organic carbon (sometimes called biogenic hydrocarbons or BVOCs) associated with increased ozone formation were estimated for the tree canopy using methods described by Scott et al. (1998). In this approach, the hourly emissions of carbon in the form of isoprene and monoterpene are expressed as products of base emission factors and leaf biomass factors adjusted for sunlight and temperature (isoprene) or simply temperature (monoterpene). Annual dry foliar biomass was derived from field data collected in Honolulu, HI, during September 2005. 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 for 2005 described in the pollutant uptake section were used as model inputs. Hourly emissions were summed to get annual totals.

The ozone-reduction benefit from lowering summertime air temperatures, thereby reducing hydrocarbon emissions from biogenic sources, was estimated as a function of canopy cover following McPherson and Simpson (1999). Peak summer air temperatures were reduced by 0.2°F for each percentage increase in canopy cover. Hourly changes in air temperature were calculated by reducing this peak air temperature at every hour based on the hourly maximum and minimum temperature for that day, the maximum and minimum values of total global solar radiation for the year. Simulation results from Los Angeles indicate that ozone reduction benefits of tree planting with "low-emitting" species exceeded costs associated with their BVOC emissions (Taha 1996). This is a conservative approach, since the benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from anthropogenic sources were not accounted for.

Reducing Stormwater Runoff

The social benefits that result from reduced peak runoff include reduced property damage from flooding and reduced loss of soil and habitat due to erosion and sediment flow. Reduced runoff also results in improved water quality in streams, lakes, and rivers. This can translate into improved aquatic habitats, less human disease and illness due to contact with contaminated water and reduced stormwater treatment costs.

Calculating Stormwater Runoff Reductions

A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 1998). The interception model accounts for rainwater intercepted by the tree, as well as throughfall and stem flow. Intercepted water is stored on canopy leaf and bark surfaces. Once the storage capacity of the tree canopy is exceeded, rainwater temporarily stored on the tree surface will drip from the leaf surface and flow down the stem surface to the ground. Some of the stored water will evaporate. Tree canopy parameters related to stormwater runoff reductions include species, leaf and stem surface area, shade coefficient (visual density of the crown), tree height, crown diameter, and foliation period. Wind speeds were estimated for different heights above the ground; from this, rates of evaporation were estimated.

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), the depth of water captured by the canopy surface, and the water storage capacity of the tree crown. Tree surface saturation was 0.04 in. Species-specific shading coefficient, foliation period, and tree surface saturation storage capacity influence the amount of projected throughfall.

Hourly meteorological and rainfall data for 2005 at the Honolulu International Airport climate monitoring station (National Oceanic and Atmospheric Administration/National Weather Service, site number: 511919, latitude: 21° 19' N, longitude: 157°567' W, elevation: 7 feet) in Honolulu, HI, were used in this simulation. The year 2005 was chosen because it most closely approximated the 10-year average rainfall of 16.2 in (410.7 mm). Annual precipitation in Honolulu during 2005 was 15.4 in (392.4 mm). Storm events less than 0.1 in (2.5 mm) were assumed not to produce runoff and were dropped from the analysis. More complete descriptions of the interception model can be found in Xiao et al. (1998, 2000).

To estimate the value of rainfall intercepted by urban trees, stormwater management control costs were based on construction and operation costs for a typical detention/retention basin in Honolulu. Twenty-year costs were annualized and divided by the amount of runoff captured in the basin over the course of a typical year (need to define better). Developers are required to construct detention/retention basins in new projects following local engineering guidelines, which were used in this analysis (City and County of Honolulu 2000). The developed area was 100 acres and the 1-acre basin was designed to hold and treat 58.2 ft^3 of runoff each year (18.9 million gal). The real estate cost for the 1-acre site was $3.75 million, or $187,567 when annualized for a 20-year period (Magota 2007). Constructing the basin was estimated to cost $131,534, or $6,577 annually (U.S. EPA 2000). Operation and maintenance costs were $719 per year. The total average annual cost was $194,863. The average annual control cost was $0.01/gal.

Property Value and Other Benefits

Trees provide a host of aesthetic, social, economic, and health benefits that should be included in any benefit–cost analysis. One of the most frequently cited reasons for planting trees is beautification. Trees add color, texture, line, and form to the landscape softening the hard geometry that dominates built environments. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality (Schroeder and Cannon 1983). Consumer surveys have shown that preference ratings increase with the presence of trees in the commercial streetscape. In contrast to areas without trees, shoppers indicated that they shopped more often and longer in well-landscaped business districts, and were willing to pay more for goods and services (Wolf 1999). Research in public-housing complexes found that outdoor spaces with trees were used significantly more often than spaces without trees. By facilitating interactions among residents, trees can contribute to reduced levels of violence, as well as foster safer and more sociable neighborhood environments (Sullivan and Kuo 1996).

Well-maintained trees increase the "curb appeal" of properties. Research comparing sales prices of residential properties with different numbers and sizes of trees suggests that people are willing to pay 3–7% more for properties with ample trees versus few or no trees. One of the most comprehensive studies on the influence of trees on residential property values was based on actual sales prices and found that each large front-yard tree was associated with about a 1% increase in sales price (Anderson and Cordell 1988). Depending on average home sale prices, the value of this benefit can contribute significantly to property tax revenues.

Scientific studies confirm our intuition that trees in cities provide social and psychological benefits. Humans derive substantial pleasure from trees, whether it is inspiration from their beauty, a spiritual connection, or a sense of meaning (Dwyer et al. 1992; Lewis 1996). Following natural disasters, people often report a sense of loss if the urban forest in their community has been damaged (Hull 1992). Views of trees and nature from homes and offices provide restorative experiences that ease mental fatigue and help people to concentrate (Kaplan and Kaplan 1989). Desk-workers with a view of nature report lower rates of sickness and greater satisfaction with their jobs compared to those having no visual connection to nature (Kaplan 1992). Trees provide important settings for recreation and relaxation in and near cities. The act of planting trees can have social value, for community bonds between people and local groups often result.

The presence of trees in cities provides public health benefits and improves the well being of those who live, work and play in cities. Physical and emotional stress has both short-term and long-term effects. Prolonged stress can compromise the human immune system. A series of studies on human stress caused by general urban conditions and city driving showed that views of nature reduce the stress response of both body and mind (Parsons et al. 1998). City nature also appears to have an "immunization effect," in that people show less stress response if they have had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, have a better outlook, and recover quicker than patients without connections to nature (Ulrich 1985). Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful effects from skin cancer and cataracts (Tretheway and Manthe 1999).

Certain environmental benefits from trees are more difficult to quantify than those previously described, but can be just as important. Noise can reach unhealthy levels in cities. Trucks, trains, and planes can produce noise that exceeds 100 decibels, twice the level at which noise becomes a health risk. Thick strips of vegetation in conjunction with landforms or solid barriers can reduce highway noise by 6–15 decibels. Plants absorb more high frequency noise than low frequency, which is advantageous to humans since higher frequencies are most distressing to people (Miller 1997).

Urban forests can be oases, sometimes containing more vegetative diversity than surrounding rural areas. Numerous types of wildlife inhabit cities and are generally highly valued by residents. For example, older parks, cemeteries, and botanical gardens often contain a rich assemblage of wildlife. Street-tree corridors can connect a city to surrounding wetlands, parks, and other greenspace resources that provide habitats that conserve biodiversity (Platt et al. 1994).

Urban and community forestry can provide jobs for both skilled and unskilled labor. Public service programs and grassroots-led urban and community forestry programs provide horticultural training to volunteers across the United States. Also, urban and community forestry provides educational opportunities for residents who want to learn about nature through first-hand experience (McPherson and Mathis 1999). Local nonprofit tree groups, along with municipal volunteer programs, often provide educational materials, work with area schools, and offer hands-on training in the care of trees.

Calculating Changes in Property Values and Other Benefits

In an Athens, GA, study (Anderson and Cordell 1988), a large front-yard tree was found to be associated with a 0.88% increase in average home resale values. In our study, the annual increase in leaf surface area of a typical mature large tree (30-year-old white ash, average leaf surface area [LSA] 3,557 ft^2) was the basis for valuing the capacity of trees to increase property value.

Assuming the 0.88% increase in property value held true for the city of Honolulu, each large tree would be worth $5,528 based on the third quarter, 2006, median single-family-home resale price in metropolitan Oahu ($712,500) (Honolulu Board of Realtors 2006). However, not all trees are as effective as front-yard trees in increasing property values. For example, trees adjacent to multifamily housing units will not increase the property value at the same rate as trees in front of single-family homes. Therefore, a citywide reduction factor (0.83) was applied to prorate trees' value based on the assumption that trees adjacent to different land uses make different contributions to property sales prices. For this analysis, the reduction factor reflects the distribution of municipal trees in Honolulu by land use. The reduction factor was based on reductions of single-home residential (100%), multi-home residential (70%), small commercial (66%), industrial/institutional/large commercial (40%), vacant/other (40%) (McPherson et al. 2001). Trees in parks were assigned a reduction factor of 0.50.

Given these assumptions, a typical large street tree was estimated to increase property values by $1.25/$ft^2$ of LSA. For example, it was estimated that a single, street-side monkeypod added about 834 ft^2 of LSA per year when growing in the DBH range of 12–18 in. Therefore, during this period of growth, monkeypod trees along streets effectively added $1,043, annually, to the value of an adjacent home, condominium, or business property (834 ft^2 × $1.25/$ft^2$ = $1,043).

Estimating Magnitude of Benefits

Resource units describe the absolute value of the benefits of Honolulu's street trees on a per-tree basis. They include kWh of electricity saved per tree, kBtu of natural gas conserved per tree, lbs of atmospheric CO_2 reduced per tree, lbs of NO_2, PM_{10}, and VOCs reduced per tree, cubic feet of stormwater runoff reduced per tree, and square feet of leaf area added per tree to increase property values. A dollar value was assigned to each resource unit based on local costs.

Estimating the magnitude of the resource units produced by all street and park trees in Honolulu required four steps: (1) categorizing street trees by species and DBH based on the city's street-tree inventory, (2) matching other significant species with those that were modeled, (3) grouping remaining "other" trees by type, and (4) applying resource units to each tree.

Categorizing Trees by DBH Class

The first step in accomplishing this task involved categorizing the total number of street trees by relative age (as a function of DBH class). The inventory was used to group trees into the DBH classes described at the beginning of this chapter.

Next, the median value for each DBH class was determined and subsequently used as a single value to represent all trees in each class. For each DBH value and species, resource units were estimated using linear interpolation.

Applying Resource Units to Each Tree

The interpolated resource-unit values were used to calculate the total magnitude of benefits for each DBH class and species. For example, assume that there are 300 monkeypods citywide in the 30–36 in DBH class. The interpolated electricity resource unit values for the class midpoint (33 in) were 211.5 kWh. Therefore, multiplying the resource units for the class by 300 trees equals the magnitude of annual cooling benefits produced by this segment of the population: 63,450 kWh of electricity.

Matching Significant Species with Modeled Species

To extrapolate from the 21 municipal species modeled for growth to the entire inventoried tree population, each species representing over 1% of the population was matched with the modeled species that it most closely resembled. Less abundant species that were not matched were then grouped into the "Other" categories described below.

Grouping Remaining "Other" Trees by Type

The species that were less than 1% of the population were labeled "other" and were categorized according into classes based on tree type (one of four life forms and three mature sizes):

- Broadleaf deciduous: large (BDL), medium (BDM), and small (BDS).
- Broadleaf evergreen: large (BEL), medium (BEM), and small (BES).
- Coniferous evergreen: large (CEL), medium (CEM), and small (CES).
- Palm: large (PEL), medium (PEM), and small (PES).

Large, medium, and small trees were >40 ft, 25–40 ft, and <25 ft in mature height, respectively. A typical tree was chosen to represent each of the above 15 categories to obtain growth curves for "other" trees falling into each of the categories:

BDL Other = Monkeypod (*Samanea saman*)

BDM Other = Rainbow shower tree (*Cassia × nealiae*)

BDS Other = Royal poinciana (*Delonix regia*)

BEL Other = Benjamin fig (*Ficus benjamina*)

BEM Other = Fiddlewood (*Citharexylum spinosum*)

BES Other = Hong Kong orchid tree (*Bauhinia × blakeana*)

CEL Other = Monterey pine (*Pinus radiata*)

CEM Other = Turkish pine; east Mediterranean pine (*Pinus brutia*)

CES Other = Bolander beach pine (*Pinus contorta* var. *bolanderi*)

PEL Other = Coconut palm (*Cocos nucifera*)

PEM Other = Date palm (*Phoenix dactilyfera*)

PES Other = Manila palm (*Veitchia merrillii*)

When local data were not measured for certain categories (e.g., CEL, CEM, CES), growth data from similar-sized species in a different region were used.

Calculating Net Benefits And Benefit–Cost Ratio

It is impossible to quantify all the benefits and costs produced by trees. For example, owners of property with large street trees can receive benefits from increased property values, but they may also benefit directly from improved health (e.g., reduced exposure to cancer-causing UV radiation) and greater psychological well-being through visual and direct contact with trees. On the cost side, increased health-care costs may be incurred because of nearby trees, due to allergies and respiratory ailments related to pollen. The values of many of these benefits and costs are difficult to determine. We assume that some of these intangible benefits and costs are reflected in what we term "property value and other benefits." Other types of benefits we can only describe, such as the social, educational, and employment/training benefits associated with the city's street tree resource. To some extent connecting people with their city trees reduces costs for health care, welfare, crime prevention, and other social service programs.

Honolulu residents can obtain additional economic benefits from street trees depending on tree location and condition. For example, street trees can provide energy savings by lowering wind velocities and subsequent building infiltration, thereby reducing heating costs. This benefit can extend to the neighborhood, as the aggregate effect of many street trees reduces wind speed and reduces citywide winter energy use. Neighborhood property values can be influenced by the extent of tree canopy cover on streets. The community benefits from cleaner air and water. Reductions in atmospheric CO_2 concentrations due to trees can have global benefits.

To assess the total value of annual benefits (*B*) for each park and street tree (*i*) in each management area (*j*) benefits were summed:

$$B = \sum_{1}^{n} j \left[\sum_{1}^{n} i \left(e_{ij} + a_{ij} + c_{ij} + h_{ij} + p_{ij} \right) \right]$$

Equation 3

where

e = price of net annual energy savings = annual natural gas savings + annual electricity savings

a = price of annual net air quality improvement = PM_{10} interception + NO_2 and O_3 absorption + avoided power plant emissions – BVOC emissions

c = price of annual carbon dioxide reductions = CO_2 sequestered – releases + CO_2 avoided from reduced energy use

h = price of annual stormwater runoff reductions = effective rainfall interception

p = price of aesthetics = annual increase in property value

Total net expenditures were calculated based on all identifiable internal and external costs associated with the annual management of municipal trees citywide (Koch 2004). Annual costs for the municipality (*C*) were summed:

$$C = p + t + r + d + e + s + cl + l + a + q$$

p = annual planting expenditure

t = annual pruning expenditure

r = annual tree and stump removal and disposal expenditure

d = annual pest and disease control expenditure

e = annual establishment/irrigation expenditure

s = annual price of repair/mitigation of infrastructure damage

cl = annual price of litter/storm clean-up

l = average annual litigation and settlements expenditures due to tree-related claims

a = annual expenditure for program administration

q = annual expenditures for inspection/answer service requests

Total citywide annual net benefits as well as the benefit–cost ratio (BCR) were calculated using the sums of benefits and costs:

Citywide net benefits = $B - C$ *Equation 4*

BCR = B / C *Equation 5*

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