A Benefit-Cost Analysis of Ten Urban Landscaping Trees in Berkeley, CA

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Abstract: A cost-benefit analysis was conducted for ten trees found in the City of Berkeley Inventory on urban forestry. Using models from previous analyses and studies, this study quantified the ecological benefits of energy conservation potential, atmospheric CO2 reductions, air quality impacts and rainwater runoff in economic and monetary terms for each of the ten species of trees: London Plane Sycamore (*Platanus acerifolia*), Purple Leaf Plum (*Prunus cerasifera*), Liquidambar (*Liquidambar styraciflua*), Camphor (*Cinnamomum camphora*), Chinese Elm (*Ulmus parvifolia*), Oriental Cherry (*Prunus serrulata*), Victorian Box Pittosporum (*Pittosporum undulatum*), Shamel Ash (*Fraxinus uhdei*), English Elm (*Ulmus procera*), Modesto Ash (*Fraxinus velutina glabra*). These benefit values were then weighed against the direct costs of tree purchase, pruning, debris removal, tree removal and watering. From the benefit-cost difference, Camphor had the highest benefits across the board in terms of energy savings, carbon sequestration, and pollutant cycling and rainfall reductions, and hence should be used as a preferential tree for urban landscaping.

Introduction

Urban forests are public investments that pay society back, enhancing the look, feel and visual identity of communities, as well as improving environmental conditions through energy conservation, air pollution filtration, and stormwater runoff reduction. Good landscaping decisions balance aesthetics and community values with economic factors such as the cost of implantation, maintenance and removal (Clark et al. 1997). The types of tree species and their planting locations in urban landscape are based on a number of factors, including species age and diversity, growth requirements, site conditions, practicality, aesthetic appropriateness, and the historic and cultural context of the surrounding areas (Gilman 1997).

Municipal urban forestry programs have sought to maintain, sustain, and enhance the community's forests through strategic landscape planning. Over the past 30 years, the City of Berkeley's Parks, Recreation, and Waterfront Department, for example, has actively planted over 30,000 trees, 5,000 of which are located in parks and along local streets and roads (City of Berkeley 2004). Under the Releaf Program of the city's Tree Policy and Tree Master Plan, Berkeley continues to plant over 800 trees a year on the streets, parks and public areas of the city (City of Berkeley 2004). However, Berkeley's municipal urban forestry programs may face new pressures in the near future due to financial constraints. As the State of California continues to deal with its budget woes, statewide funding for municipal redevelopment and public works must be constrained. Allocating resources for urban forestry tend to be lower priority when cities and counties prioritize funding amongst competing needs. In this context, urban landscaping requires more cost-effective and efficient solutions to make wise use of limited funding.

The purpose of this study is to provide a quantitative and qualitative comparison of landscaping trees commonly used in Berkeley, to provide meaningful recommendations regarding which species can maximize present and future economic benefits, in terms of both direct financial costs and ecological processes. This will simultaneously protect community interests and promote informed decisions about future urban forestry management. Whereas previous landscaping decision making was motivated by aesthetic and personal preference issues, the economic analysis provided by this study will provide valuable statistical evidence for preferential species planting in urban environments.

This study analyzes tree suitability for urban forestry landscaping by looking at ten tree species commonly planted in Berkeley and determining the tree species' potential to conserve energy, reduce atmospheric CO2, and filter air pollutants. This study also evaluates total annual landscaping and maintenance costs in terms of initial purchase, implantation, and maintenance, as well as watering costs.

The following ten trees were selected for detailed evaluation in this study because they are among the most abundant trees in Berkeley based on a 1990 street tree inventory (City of Berkeley 2000):

- Sycamore, London Plane (*Platanus acerifolia*)
- Plum, Purple Leaf (*Prunus cerasifera*)
- Liquidambar (*Liquidambar styraciflua*)
- Camphor (*Cinnamomum camphora*)
- Elm, Chinese (*Ulmus parvifolia*)
- Cherry, Oriental (*Prunus serrulata*)
- Pittosporum, Victorian Box (*Pittosporum undulatum*)]
- Ash, Shamel (*Fraxinus uhdei*)
- Elm, English (*Ulmus procera*)
- Ash, Modesto (*Fraxinus velutina glabra*)

Brief descriptions of each species' ecology and characteristics can be found in Table 1. Most of the above-listed species are ornamental trees, not native to the Berkeley area, but do well in the region's Mediterranean-type climate and have characteristics suitable for street trees. These qualities include, but are not limited to, rapid growth, relatively low water maintenance requirements, tolerance to various soil pHs and nutrient availability, non-serious pest attractants, and various aesthetic qualities, such as leaf and flower size and color.

According to the City of Berkeley (2004) records, London Plane Sycamore (*Platanus acerifolia*) is one of the largest and also archetypal species of landscaping trees in the City of Berkeley. An inventory by Thomas J. Pehrson in the late 1980s found *P. acerifolia*, as one of the most abundant species in the Berkeley area, constituting more than 29% of all trees in Berkeley. Also, it constitutes almost 23% of trees planted, the largest percentage of all others. Purple leaf plum (*Prunus cerasifera*) is the second most urban landscaped tree in the city of Berkeley constituting 18% of all of those used for planting, and it already constitutes 22% of all trees in the City of Berkeley. Since the decision to use this tree in 1972, an estimated 1,800 *P. cerasifera* trees have been planted in the city of Berkeley. Chinese Elm (*Ulmus parvifolia*), the third species of tree most highly used in urban landscaping in the Berkeley area. It constitutes 14% of all trees currently planted in Berkeley, and 16% of those used for landscape planting.

The economic investigations involved in this study will determine whether these mostly highly used trees can be substituted for less costly and more ecologically beneficial alternatives.The Center for Urban Forest Research has made significant strides in attempting to compile methods and results for studies regarding urban landscaping and quantifiable ecological factors. In California, Professors at the University of California at Davis have conducted several studies regarding each specific elements of urban forestry, such as effects on hydrology (Larsen et al. 2001), neighborhood-scale temperature variation (Levitt et al. 1994), and even holistic cost-benefit analyses of urban trees themselves (McPherson 2001, 2003). Whereas their studies examined certain species of trees in different regions, they have yet to apply their study techniques to the species used in Berkeley urban forestry. Their methodology and mathematical research serves as a strong basis for the investigative study of the ten trees of Berkeley.

Table 1(a): Tree Characteristics and brief descriptions for ten of the tree species used for urban landscaping in Berkeley, CA.

(London Plane Sycamore, Purple Leaf Plum, Chinese Elm, American Sweet Gum, & Camphor)

Characteristic	**London Plane Sycamore (Platanus acerifolia)**	**Purple leaf plum (Prunus cerasifera)**	**Chinese Elm (Ulmus parvifolia)**	**American Sweet Gum (also Liquidambar) (Liquidambar styraciflua)**	**Camphor (Cinnamomum camphora)**
Type	Deciduous	Deciduous	Deciduous	Deciduous	Evergreen
Height	15-25'	25 ft	50 ft.	60-70' (less frequently to 100')	50-100'
Spread	10-20'	15 to 20'	(50' tall)	20-30'	twice as wide as it is tall
Environmental Preference	warmer temperate climates	Full sun, partial shade. Moist, well-drained soil.	Sunny. moist, well-drained soils	Full sun, easily grown in average, medium wet, well-drained soils, not reliably winter hardy throughout USDA Zone 5 (particularly northern portions)	Well Drained, Full Sun / Partial Shade
Leaf size	6" to 7" long and up to 10" wide	5-7 cm (1.5 to 2.5")	15-20’	4-6" across with 5-7 lobes	Evergreen, alternate, simple, ovate to obvate, to 5 inches, margins entire and somewhat wavy, dark glossy green avove, pale yellow below, with three prominent veins, with a camphor ordor when crushed
Flower size	Small white clusters in Fall 2-3 cm across in diameter.	White or pink, 2-3 cm across. Early Spring.	White, purple flowers 2-3 cm in diameter.	Monoescious, small, bright yellow green (tinged with red) and not showy. Early to mid Spring. No flower for first 15 to 20 years	Somewhat showy and fragrant, greenish white to pale yellow, small and borne on 3-inch panicles

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Fruiting bodies	3 cm (1" diameter fruits), borne in 2's and 3's	Succulent, indehiscent, drupe. 1" in diameter	rounded samaras, 0.75" to 2.25" long, 0.33" to 1" wide	Spiny "gumballs", woody brown spehерical cluster of capsules, 1 to 1 1/2" diameter; No fruit for first 15 to 20 years	Dark blue to black, round, fleshy drupes that are borne on green stalks, usually produced in abundance
Growth Rate	12 to 18 inches	12 inches (30cm) Average growth per year in first 10-20 years	Moderate to fast, more than 18 inches per year	Fast growing	12-24"
Pollen Production	7840.3 grains of pollen/m3	350 grains/ m3	450 grains/ m3	130 grains/ m3 Minor Threat	150 grains / m3
Lifespan (Longevity)	70 years	Short lived. 20 years	80 years	Greater than 100 years	100-150 years
Disease resistance	intermediate	intermediate	high	high	intermediate
Disease and pest Susceptibility	Plane Anthracnose Apiognomonia veneta, canker, powdery mildew American plum borer, sycamore lacebug	Aphids, shot hole borer, peach tree borer, scale, tent caterpillars canker, leaf spot. does not like compacted soil	Dutch Elm	Aphids / Caterpillars / Scales / Spider Mites	Scales / Mites
Diameter at tree maturity (dbh)	7 to 12	0 to 6	1 to 6	2 to 6	7 to 12

Table 1(b): Tree Characteristics and brief descriptions for ten of the tree species used for urban landscaping in Berkeley, CA.
(Kwasan Japanese Flowering Cherry, Victoria Box, Shamel Ash, English Elm, & Modesto Ash)

Characteristic	Kwasan Japanese Flowering Cherry (Prunus serrulata)	Victorian Box Pittosporum (Pittosporum undulatum)	Ash, Shamel (Fraxinus uhdei)	English Elm (Ulmus procera)	Modesto Ash (Fraxinus velutina glabra)
Type	Deciduous	Evergreen	Deciduous	Deciduous	Deciduous
Height	25'-30'	30-40'	80 ft	>66	50'
Spread	24'	30-40'	>66	>66	30'
Environmental Preference	Moist, full sun/partial shade	Full sun/partial shade	Very Acidic / Slightly Acidic / Neutral / Slightly Alkaline / Very Alkaline Soil_Texture: Clay / Loam / Sand Soil Moisture: Moist / Dry Exposure: Full Sun / Partial Shade	Moist, full sun/partial shade	Clay / Loam / Sand Soil Moisture: Moist / Dry Exposure: Full Sun / Partial Shade
Leaf size	4 to 8"	Medium to dark green, glossy, wavy-edged, 6-8 inches long.	15-28 cm long, leaflets 5-9, 7-11 cm long, 2-4 cm wide		Leaflet blade length: 2 to 4 inches; less than 2 inches with a single leader; no thorns
Flower size	Profuse, frangrant spring flowers can be single or double, white or a shade of pink, from half an inch to almost 3 increase across	Fragrant creamy-white flowers in the spring	13-20 cm long in panicles		

Characteristic	**Kwasan Japanese Flowering Cherry (Prunus serrulata)**	**Victorian Box Pittosporum (Pittosporum undulatum)**	**Ash, Shamel (Fraxinus uhdei)**	**English Elm (Ulmus procera)**	**Modesto Ash (Fraxinus velutina glabra)**
Fruiting bodies	Typically no fruit since the "Kwanzan" variety is sterile, the species P. serrulata produces a small red cherry	Yellowish-orange fruit open in fall to show sticky golden-orange seeds.	0.8 to 1.6 inches (2-2 cm) in late spring		Single samaras (dry fruit bearing wings)
Growth Rate	24" per year	Slow to moderate	fast growing tree, up to 80 fet tal (24 m) in 30 years,	1.5-2 ft (45-60 cm) per year; Max Growth Rate (in/season): 36 / >37	Max Growth Rate (in/season): 36 -- fast
Pollen Production			100 grains/ m3	250 grains/ m3	100grains/ m3
Lifespan (Longevity)	50-100 years	50-100 years	Average - 50 to 150 years	Very Long - greater than 150 years	Average - 50 to 150 year
Disease resistance	intermediate	low	Oak Root Fungus	intermediate	Oak Root Fungus / Powdery Mildew
Disease and pest Susceptibility	Disease: Canker / Crown Rot / Oak Root Rot / Phytophthora / Root Rot / Rust / Verticillium; Pest: Caterpillars	Aphids / Scales	Fusarium / Root Rot / Sooty Mold / Verticillium Pest Susceptibility: Aphids / Scales / White Fly	Dutch Elm Disease / Oak Root Rot / Phytophthora / Root Rot / Sooty Mold / Verticillium; Aphids / Beetle Borers / Beetle Leaves / Scales	Anthracnose / Misletoe / Root Rot / Rust / Sooty Mold / Verticillium Pest Susceptibility: Beetle Borers / Psyllid / Spider Mites / White Fly
Diameter at tree maturity (dbh)	12	0 to 6	7 to 10	5 to 10	7 to 12

Methods

Benefits and costs are directly connected to tree size variables such as trunk diameter at breast height (DBH), tree canopy cover, and leaf surface area (LSA). For instance, pruning and removal costs usually increase with tree size expressed as DBH. DBH is defined as the diameter of the trunk 4.5 feet (1.4 meters) above the base of the tree. Some costs, such as sidewalk repair, are negligible for young trees but increase as tree roots grow large enough to heave pavement. For other parameters, such as air pollutant uptake and rainfall interception, benefits are related to tree canopy cover and leaf area.

Prices were assigned to each cost (e.g., planting, pruning, removal, irrigation, infrastructure repair, liability) and benefit (e.g., heating/cooling energy savings, air pollution absorption, stormwater runoff reduction) through direct estimation and implied valuation of benefits as environmental externalities. Most benefits occur on an annual basis, but some costs are periodic. For instance, street trees may be pruned on regular cycles but are removed in less regularly, such as when they pose a hazard or soon after they die. Most costs and benefits are presented on an average annual basis.

The sum of all annual benefits (B) is given by the formula:

B = E + A + C + H, where
E = energy savings
A = air quality improvement
C = carbon dioxide reductions
H = stormwater runoff reductions

Energy Savings (E) Due to significant changes in temperature, shading trees can be a significant method to cool down streets, community areas and especially buildings during warm periods. The shading, evapotranspiration and wind speed reduction offered by various trees can significantly affect urban energy use requirements, and reduce the necessity for air conditioning and cooling fans. Due to increases in CO_2 emissions from power plants, ozone depletion, and human activity, these energy savings can result in significant financial savings.

Using a program and mathematical model developed in 1998 by the Sacramento Municipal Utilities District, and endorsed by the American Public Power Association (APPA), the amount of energy saved from a certain species of tree was estimated from certain variables, such as tree species, tree age, orientation (i.e. north, south, east, west), and distance from the building. By calculating the shade cover and the energetic outputs given certain crown size of a species, and comparing that with overall temperature change, the program then calculates the kilowatt hours (KwH) saved, the kilowatt (Kw) savings and the carbon and CO_2 sequestration. This study assumed savings from a mature tree with a standard northwest orientation, zero to fifteen feet (0-4.6 meters) from a building.

Based on data from the California Energy Commission, average 2004 electricity prices for California were $0.1280/ Kwh. From estimated annual Kwh saved from trees, average annual savings are calculated by:

Energy Savings (E) = (Kwh saved per species) * $0.1280 / Kwh

Improving Air Quality (A) Trees improve air quality through a variety of ways. Trees absorb pollutants such as ozone and nitrogen oxides, intercept particulate matter, release oxygen through photosynthesis, transpire water, and shade surfaces. The amount of pollutants deposited as dry mass on dry surfaces or into organic matter is given by the pollutant dry deposition, or PDD. The PDD per tree is proportional to the size of the canopy, canopy density, and the leaf area index. The LAI is the ratio of leaf surface area to crown projection area. For simplicity, PDD is expressed as the product of a pollutant concentration (C) and canopy projection area (CP). CP is calculated based on the tree spread, and the area underneath the dripline.

PDD = C x CP.

Applying the principle from McPherson, E.G., J.R. Simpson, P.J. Peper and Q. Xiao (1999), air quality benefits are estimated using a surrogate of the market value of pollutant emission. If an industry is willing to pay $1 per pound for an air quality mitigation credit, then the air pollution mitigation value of a tree that absorbs or intercepts one pound of air pollution would be $1.

Air Quality Improvement (A) = Value of PDD = Pollutant Emission value x PDD

Atmospheric Carbon Dioxide Reductions (C) Trees have been found to directly sequester carbon dioxide as woody and foliar biomass as they grow, and provide significant cooling effects from shading and windbreaks, reducing energy consumption. As with energy savings, the APPA

Carbon Sequestration model was used to derive atmospheric carbon dioxide reductions. Carbon sequestration, the net rate of carbon dioxide storage in above- and below-ground biomass over the course of one growing season, was calculated applying tree species and age. The amount of carbon sequestered each year is the annual increment of carbon stored as trees increase in biomass each year. This study applied information for a mature tree in the APPA model.

An average value of $48.75 per metric ton of carbon was used to calculate the estimate annual savings of carbon sequestration, via programs and overall pollution effects (Stavins, Richards 2004). This figure is based on heuristic estimates of costs associated with program management, clean-up, restoration, and policy implementation.

Atmospheric Carbon Dioxide Reductions (C) = Amt. of CO2 sequestered * $48.75

Stormwater Runoff (H) Trees serve an important role in reducing storm water runoff and increasing the rate of groundwater recharge. Trees absorb rainfall in their leaves and their branch surfaces areas, reducing the volume of water that runs off into storm drains. Intercepted water is stored temporarily on the canopy leaves and the bark surfaces. Once the leaf is saturated, it drips from the leaf surface and flows to the ground or evaporates. In addition, root growth increases the capacity and rate of soil infiltration by rainfall and reduces the amount of storm water runoff.

The Xiao et al. (1998, 2000) numerical simulation mode was used to estimate the annual rainfall interception and fall and stem flow. Tree canopy parameters include species, leaf area, shade area of the crown, and tree height. The volume of water stored in the tree crown was calculated from crown projection area, leaf area index and water depth on the canopy surface. The total surface area of the leaves and the amount of storage that a unit of leaf area can retain are the most important factors determining the rain interception. LAI values were given by the USDA Forest Services (2002). Average crown volumes were calculated from average height and average leaf masses.

To estimate the monetary value of rainfall interception, stormwater management control costs were used based on minimum requirements for stormwater management (Herrera Environmental Consultants 2001). For a 10-acre, single-family residential development on permeable soils (e.g., glacial outwash or alluvial soil) it costs approximately $20.79/Ccf ($0.02779/gal [$.00011/m3]) to treat and control flows stemming from a 6-month, 24-hr storm event.

Rainfall Interception savings (H) = LAI x [$.00011/m3] * crown volume

COSTS

The sum of all costs is given by the formula:

C = T + P + D + R + S + W, where
T = initial purchase cost
P = average annual tree pruning cost
D = average annual organic debris and storm clean-up cost
R = average annual cost to repair/mitigate infrastructure damage
S = annual tree and stump removal and disposal cost
W = annual watering and irrigation cost

Initial Purchase Cost (T) Initial purchase cost encompasses the market price of a container plant. For trees, the market price depends on the caliper size or diameter of the trunk at breast height (DBH). Costs were derived from average price index for national tree nurseries.

Maintenance Costs Maintenance costs encompass the expenditures for pruning, removal of organic debris like leaf litter, repair of sidewalks and other infrastructure, and removal of the tree at the end of its life. The Berkeley Job Classification and Salary Listing (2004) details the responsibilities and annual salary of various positions in urban landscaping. Hourly wages were estimated based on median salary ranges for each position divided by 168 hours for roughly 21 working days in a month. Monetary figures for the labor costs were generated by estimating the average annual amount of work for each area of maintenance.

Average Annual Tree Pruning Cost (P). The cost of pruning includes the hourly cost of labor to cut, haul, and dispose of the branches. The time and labor it takes to prune depends on the amount needed to be prune, which is correlated to 1 hour of work per unit of annual growth. Assuming that the tree is maintained at their standard height and crown width specifications, it is the annual tree growth that is pruned.

It is the collective responsibility of two Laborers and one Landscape Equipment Operator to prune each tree to desired specifications. Their combined hourly wage multiplied by the time spent for annual pruning, as proportional to tree growth, yields the annual cost of pruning and disposal. This study assumes that the same laborers who prune the trees are also the same ones responsible for hauling and disposal.

Average Annual Tree Pruning Costs (P) = (Hourly cost / inch) * inches of annual growth

Average Annual Organic Debris Removal cost (D). Organic debris is defined as the amount of leaf litter, fruiting bodies or seed pods generated through annual growth. It requires a significant amount of daily maintenance, cleaning and removal by mainly a groundskeeper and various city custodial or public works employees, as well as weekly street cleaning and maintenance. The average annual per tree cost for litter clean-up (i.e., street sweeping) was $1.57 ($0.12/in [$0.30/cm] DBH) (McPherson 2004).

Average Annual Organic Debris Removal Costs (D) = ($0.12 / in) * Inches of annual growth

Average Annual Cost to Repair/Mitigate Infrastructure Damage (R). The damage on hard surfaces such as pavement, asphalt and sidewalks, resulting from uprooting and shallow growth can be significant in terms of construction, repair and labor costs incurred by the city. Although studies have found litigation settlements for damages from fallen trees and branches, legal staff, costs of employee insurance and tree replacement costs to be significant additional costs, these aspects are beyond the scope of this study. This study analyzes the physical labor costs of employees and equipment required to repair hard surfaces on an annual basis.

The overall incidences of surface damage costs are related to root length and growth rate. The rate of root growth is proportional to the overall tree growth rate. Root damage costs include labor costs to repair damage from overgrowth and upwelling. This is the responsibility of the two Laborers, two Landscape Equipment Operators, a Landscape Gardener, Landscape Gardener Supervisor, and a Trainee.

Average Annual Costs to Repair/Mitigate Infrastructure Damage (R) = (repair costs/ inch of growth) * Inches of root growth.

Average Annual Tree and Stump Removal and Disposal Cost (S). Removal cost revolves around the labor costs and is directly related to the lifespan of the trees. Removal occurs at the end of a tree's life trees or when the tree becomes unmanageable or diseased. Tree death due to disease cannot be estimated, due to variability of conditions, so this study considers only lifespan as an element of removal. The costs of removal includes the cost of labor for the cutting down of the tree, the hauling of the debris, and disposal costs. This typically involves three laborers, two landscape equipment operators, one landscape gardener supervisor, and a trainee. A more involved study into the costs for removing public and private trees found that it cost $18 and $12 per inch ($46 and $30/cm) DBH, respectively. Stump removal and wood waste disposal costs were $7/in ($18/cm) DBH for public trees. The total labor cost for tree removal and waste disposal was $26/in ($66/cm) DBH. (McPherson 2003). The cost of tree removal and disposal is distributed over the lifespan of the tree, in order to factor in the frequency of tree removal. Trees with shorter lifespans will need to be removed sooner and more than long-lived trees.

Average Annual Tree and Stump Removal and Disposal Cost (S) = Total Growth * (labor cost/year = $26 / in) / lifespan

<u>Average Annual Water and Irrigation Costs (W).</u> Once planted, 15-gal trees typically require 100-200 gal (0.4-0.8 m3) per year during the establishment period. It is assumed that water was purchased at a price of $1.76 Ccf (Portland Water District 2001). Hence, total annual irrigation water cost was assumed to increase with tree leaf area. Due to the variability of leaf area and crown size and shape for each species, average height and maximal values of DBH were substituted to find the trunk volume for use in the calculations. Also, due to limitations of absorbency and over saturation of soil, it was assumed that three gallons of water were used per cubic foot of tree. Using these assumptions, total annual water cost was calculated by:

Water usage (W) = (Water cost = 1.76/gallon) * (cu. Ft. of trunk * 3 gallons/ cu. ft)

Data

Based on the above calculations, several tables were created, compiling data from each of the selected areas. Table 2 lists the raw ecological values associated with each of the criteria for each of the ten species of trees. Table 3 lists the values of each of the criteria in monetary terms according to the monetary value calculations found in the literature research. Table 4 lists the costs associated with various elements of tree maintenance, as well as initial purchase costs and watering. Summarized in Table 5, the total annual costs per tree associated with each species were subtracted from the total annual benefits derived from each tree. Additional qualitative values and non-quantifiable elements were also listed for later comparisons.

TABLE 2 – ECOLOGICAL BENEFITS VALUES

Characteristic	London Plane Sycamore (Platanus acerifolia)	Purple leaf plum (Prunus cerasifera)	Chinese Elm (Ulmus parvifolia)	Liquidambar (Liquidambar styraciflua)	Camphor (Cinnamomum camphora)	Oriental Cherry (Prunus serrulata)	Victorian Box Pittosporum (Pittosporum undulatum)	Shamel Ash (Fraxinus uhdei)	English Elm (Ulmus procera)	Modesto Ash (Fraxinus velutina glabra)
Energy savings										
- KW saved	0.19	0.15	0.15	0.20	0.20	0.05	0.05	0.20	0.19	0.15
- KWH saved	486.49	385.53	385.53	530.43	530.43	93.19	93.19	530.43	486.49	385.53
Annual Carbon Sequestration										
- Carbon (kgs)	68.31	37.65	37.65	68.31	68.31	16.83	16.83	68.31	68.31	37.65
- CO2 (kgs)	250.70	138.16	138.16	250.70	250.70	61.73	61.73	250.70	250.70	138.16
PDD										
- Ozone (O3)	450.00	510.00	1500.00	750.00	4500.00	720.00	1050.00	1980.00	1980.00	900.00
- Sulfer Oxides (SOx)	18.00	20.40	60.00	30.00	180.00	28.80	42.00	79.20	79.20	36.00
- Nitrogen Oxides (NOx)	20.55	23.29	68.50	34.25	208.50	32.88	47.95	90.42	90.42	41.10

TABLE 3 – AVERAGE ANNUAL BENEFITS CHART

Characteristic	London Plane Sycamore (Platanus acerifolia)	Purple leaf plum (Prunus cerasifera)	Chinese Elm (Ulmus parvifolia)	Liquidambar (Liquidambar styraciflua)	Camphor (Cinnamomum camphora)	Oriental Cherry (Prunus serrulata)	Victorian Box Pittosporum (Pittosporum undulatum)	Shamel Ash (Fraxinus uhdei)	English Elm (Ulmus procera)	Modesto Ash (Fraxinus velutina glabra)
Energy Savings (E)	62.27	49.35	49.35	67.90	67.90	11.93	11.93	67.90	62.27	49.35
Carbon Sequestration (C)	12221.63	6735.30	6735.30	12221.63	12221.63	3009.34	3009.34	12221.63	12221.63	6735.30
Air Quality (A)	488.55	553.69	1628.50	814.25	4888.50	781.68	1139.95	2149.62	2149.62	977.10
Rainfall Interception (H)	0.79	0.02	0.16	0.28	0.55	0.28	0.34	0.30	0.52	0.36
TOTAL BENEFITS (B)	12773.24	7338.36	8413.31	13104.05	17178.57	3803.23	4161.56	14439.44	14434.04	7762.11

TABLE 4 – AVERAGE ANNUAL COSTS CHART

Characteristic (In Dollars)	London Plane Sycamore (Platanus acerifolia)	Purple leaf plum (Prunus cerasifera)	Chinese Elm (Ulmus parvifolia)	Liquidambar (Liquidambar styraciflua)	Camphor (Cinnamo-mum camphora)	Oriental Cherry (Prunus serrulata)	Victorian Box Pittosporum (Pittosporum undulatum)	Ash, Shamel (Fraxinus uhdei)	English Elm (Ulmus procera)	Modesto Ash (Fraxinus velutina glabra)
Initial purchase cost (T) Based on Caliper Size										
- 1 1/2"	$115.00	25	$85.00	165	135	165	110	115	115	115
- 2 1/2"	225	32	175	335	260	335	220	255	255	255
- 2 1/2 -3"	335	37	195	450	350	450	310	335	335	335
- 3 1/2 -4"	425	60	300	700	450	700	440	425	425	425
Annual maintenance costs										
- Pruning (P)	1028.00	771.60	1157.40	1414.60	1157.40	1543.20	771.60	1157.40	1543.20	2314.80
- Debris Removal (D)	1.92	1.44	2.16	2.64	1.92	2.88	1.44	2.16	2.88	4.32
- Root Damage (R)	2525.60	1894.20	2841.30	3472.70	2525.60	3788.40	1894.20	2841.30	3788.40	5682.60
- Tree/ stump removal (S)	4.37	265.20	195.00	78.00	312.00	99.84	143.52	205.92	137.28	93.60
Water Usage (W)	82.90	25.93	51.80	67.37	310.86	111.90	36.27	230.21	190.08	207.24
TOTAL COST (C)	**4067.79**	**3018.37**	**4547.66**	**5735.31**	**4757.78**	**6246.22**	**3287.03**	**4861.99**	**6086.84**	**8727.56**

TABLE 5 – BENEFITS-COSTS CHART, and NON-QUANTIFIABLE CHARACTERISTICS

	London Plane Sycamore (Platanus acerifolia)	Purple leaf plum (Prunus cerasifera)	Chinese Elm (Ulmus parvifolia)	Liquidambar (Liquidambar styraciflua)	Camphor (Cinnamomum camphora)	Oriental Cherry (Prunus serrulata)	Victorian Box Pittosporum (Pittosporum undulatum)	Shamel Ash (Fraxinus uhdei)	English Elm (Ulmus procera)	Modesto Ash (Fraxinus velutina glabra)
TOTAL BENEFITS (B)	12773.24	7338.36	8413.31	13104.05	17178.57	3803.23	4161.56	14439.44	14434.04	7762.11
TOTAL COST (C)	4067.79	3018.37	4547.66	5735.31	4757.78	6246.22	3287.03	4861.99	6086.84	8727.56
BENEFITS-COSTS	8705.45	4319.99	3865.65	7368.74	12420.79	-2442.99	874.53	9577.45	8347.20	-965.45
Fruiting bodies	3 cm (1" diameter fruits), borne in 2's and 3's	Succulent, indehiscent, drupe. 1" in diameter	rounded samaras, 0.75" to 2.25" long, 0.33" to 1" wide	Spiny "gumballs", woody brown speherical cluster of capsules, 1 to 1 1/2" diameter; No fruit for first 15 to 20 years	Dark blue to black, round, fleshy drupes that are borne on green stalks, usually produced in abundance	Typically no fruit since the "Kwanzan" variety is sterile, the species P. serrulata produces a small red cherry	Yellowish-orange fruit open in fall to show sticky golden-orange seeds.	0.8 to 1.6 inches (2-2 cm) in late spring		Single samaras (dry fruit bearing wings)
Pollen Production	7840.3 grains of pollen/m3	350 grains/ m3	450 grains/ m3	130 grains/ m3 Minor Threat	150 grains / m3			100 grains/ m3	250 grains/ m3	100grains/ m3
Disease resistance	intermediate	intermediate	high	high	intermediate	intermediate	low	Oak Root Fungus	intermediate	Oak Root Fungus / Powdery Mildew

	London Plane Sycamore (Platanus acerifolia)	Purple leaf plum (Prunus cerasifera)	Chinese Elm (Ulmus parvifolia)	Liquidambar (Liquidambar styraciflua)	Camphor (Cinnamomum camphora)	Oriental Cherry (Prunus serrulata)	Victorian Box Pittosporum (Pittosporum undulatum)	Shamel Ash (Fraxinus uhdei)	English Elm (Ulmus procera)	Modesto Ash (Fraxinus velutina glabra)
Disease and pest Susceptibility	Plane Anthracnose Apiognomonia veneta, canker, powdery mildew American plum borer, sycamore lacebug	Aphids, shot hole borer, peach tree borer, scale, tent caterpillars canker, leaf spot. does not like compacted soil	Dutch Elm	Aphids / Caterpillars / Scales / Spider Mites	Scales / Mites	Disease: Canker / Crown Rot / Oak Root Rot / Phytophthora / Root Rot / Rust / Verticillium; Pest: Caterpillars	Aphids / Scales	Fusarium / Root Rot / Sooty Mold / Verticillium Pest Susceptibility: Aphids / Scales / White Fly	Dutch Elm Disease / Oak Root Rot / Phytophthora / Root Rot / Sooty Mold / Verticillium; Aphids / Beetle Borers / Beetle Leaves / Scales	Anthracnose / Misletoe / Root Rot / Rust / Sooty Mold / Verticillium Pest Susceptibility: Beetle Borers / Psyllid / Spider Mites / White Fly

TABLE 5 – BENEFITS-COSTS CHART, and NON-QUANTIFIABLE CHARACTERISTICS (cont.)

Results

Benefits. Relationships between tree species and performance can best be explained by its size for the criteria discussed. Based on the ecological data compiled in Table 2, the size of the tree species has a significant impact on its performance for each of the criteria. Table 3 outlines the specific value benefits associated with each of the ten tree species. The larger trees provide the most amounts of energy savings for both kilowatts and kilowatt hours. The large size of the tree grants them significant shade cover potential to public and industrial areas. Furthermore, the data indicates a trend relating the size of the tree to the amount of carbon sequestered in tissues. Larger trees sequester more carbon and CO_2 from the atmosphere, due to their larger biomass.

As for air quality improvements, because the calculation relied on canopy cover to estimate chemical cycling, the trees with broader canopy cover had a larger surface area for dry deposition. Therefore, those trees had a distinct advantage in regards to air quality improvement potential. However, no noticeable trend typifies the tree species for annual filtration of ozone, sulfur oxides, and nitrous oxides. A similar assessment applies to rainfall interception and stormwater runoff reductions.

For the highest average annual energy savings, three species- Liquidambar, Camphor and Shamel Ash- save the most at $67.90 annually per tree. Oriental Cherry and Victorian Box Pittosporum had the lowest rate of energy savings at $11.93 annually per tree. In terms of carbon sequestration, in addition to the three previous best performers, London Plane and English Elm also contribute savings of up to $12,221.63 annually per tree. Oriental Cherry and Victorian Box Pittosporum had the lowest rate of carbon savings at $3,009.34 annually per tree.

Camphor is the most effective in improving the air quality, with savings of $4888.50, more than twice as much as the other competitors. In terms of overall monetary benefits, Camphor resulted in the highest monetary benefit savings with $17178.57 in annual savings per tree, while Oriental Cherry had the lowest benefits with $3803.23 annual savings per tree.

Costs. Table 4 provides details on the costs for varying prices associated with maintenance and water usage. For initial purchase price, values for a 3.5 - 4 inch caliper sized trunk was used as the measurement of a mature size tree. Overall, Modesto Ash was found to be the most expensive species for annual maintenance at $8727.56, while Purple Leaf was the least expensive at $3018.37 per year.

Net Benefit and Cost. When taking the difference between the estimated benefits of each species from the overall costs of maintenance, a relative estimate of intrinsic valuation for each species was found, and summarized in Table 5. Based on these quantitative results, Camphor is the best species to plant to maximize net benefit from the costs. Also, as discussed previously, Camphor had the highest benefits across the board in terms of energy savings, carbon sequestration, and pollutant cycling and rainfall reductions. As for overall rankings, based solely upon the monetary benefits derived from this study, the following list describes the preferential order of planting:

1. Camphor (*Cinnamomum camphora*)
2. Ash, Shamel (*Fraxinus uhdei*)
3. Sycamore, London Plane (*Platanus acerifolia*)
4. Elm, English (*Ulmus procera*)
5. Liquidambar (*Liquidambar styraciflua*)
6. Plum, Purple Leaf (*Prunus cerasifera*)
7. Elm, Chinese (*Ulmus parvifolia*)
8. Pittosporum, Victorian Box (*Pittosporum undulatum*)]
9. Ash, Modesto (*Fraxinus velutina glabra*)
10. Cherry, Oriental (*Prunus serrulata*)

Of the ten tree species planted, Oriental Cherry performed the least well in both categories. In terms of the monetary benefits for each of the given criteria, Oriental Cherry only returned a total of $3803.23 annually per tree back to the city. This may be attributable to the relatively small size of the tree, and method of calculation. As for costs, it was the second most expensive tree to plant and maintain at a total annual cost of $6246.22, falling behind only to Modesto ash at $8727.56. Pruning and root damage were one of the main contributors to its high cost. When ultimately subtracting the costs from the benefits, Oriental cherry had a net return to the city at a value of $-2442.99, meaning it costs more for the city to maintain this tree, than to reap its benefits.

As for the London Plane Sycamore, Purple Leaf Plum, and Chinese Elm, the three trees most highly used in Berkeley Urban Landscaping, though not the best performer based on the criteria, each one resulted in net benefits to the city. London Plane Sycamore was actually the third best performer, with a net annual return to the city of $8705.45 per tree. Purple Leaf Plum was sixth best performer at a net annual return of $4319.99, and Chinese Elm seventh at $3865.65. Therefore, while these three species are still positive performers, there are better alternatives which can result in greater savings to the city, such as Camphor, Shamel Ash, English Elm, and Liquidambar.

However, while quantitative analyses may provide monetary valuation in support of economic decision-making, there are certain non-quantifiable values, which provide strong enough practical sway to shade opinions. For example, allergens are a significant health concern to the 50 million Americans spending over $18 billion a year in healthcare costs for allergic diseases, including asthma, rhinitis and sinusitis (AAAI 2001) and to the 36% of the total American population that suffers from allergies directly related to tree and plant pollen (APHA 2002). As for the city of Berkeley, it is important to the over 100,000 residents, 18,000 families and 12,000 children living in the city (US Census Bureau 2002). Increased incidence and exposure to certain species may trigger a widespread allergy epidemic among the residents of the city. While this study did not fully discuss the scientific reactivity of populations to these tree species, preliminary observations were briefly discussed in the recommendations of this study.

In-depth quantitative valuation of how tree aesthetics contribute to both property values and community worth are an involved area within itself, and far beyond the scope of this study. This valuation process involves complex appraisal methods which compare purchasing prices for homes with the trees of interest, against those without to gauge the additional value to property.

In addition, this study is limited to the weight given to the criteria selected and the methods used for valuation. While these criteria are important in a global landscape, other qualities may be of more significant value than those examined in this study. This includes the qualitative values such as public health hazards, personal preference, and even the cultural or historical contexts of planting. In addition, while these methods and the studies they are based upon are thorough and comprehensive analyses, there is a multitude of variables which may skew pricing values more significantly. However, these studies are as honest a representation as others.

Conclusion

Despite the shortcomings of benefit-cost studies of this nature, they are valuable tools which can affect future decision-making for city and urban improvement. They have become a method of providing statistical evidence to provide environmental economists the numerical evidence to support their exclamations. By providing this information in the form of monetary terms, it becomes much more substantial to policy makers and planners alike. It has successfully led to improved resources allocation, more efficient policy, better alternatives and stronger overall organization. Further studies will continue to employ these valuation methods, as quantitative analyses for various ecological processes become an ever-growing element of city development decisions. They provide the necessary statistical support to valuate systematic ecological processes, without delving into the deeper nuances of philosophical and moral grounds. It becomes a necessary tool for ecologists and biologists to persuade others of the importance of valuing seemingly, non-practical environmental processes.

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