Assessment of Ecosystem Services Provided by Urban Trees:

Public Lands Within the Urban Growth Boundary of Corvallis, Oregon

TECHNICAL REPORT

Prepared by: Don Phillips, Ph.D., Research Biologist, U.S. Environmental Protection Agency, Western Ecology Division, Corvallis, OR

In collaboration with: Connie Burdick, Geographer, U.S. Environmental Protection Agency, Western Ecology Division, Corvallis, OR
Becky Merja, City Forester, Parks and Recreation Department, City of Corvallis, OR
Norm Brown, Arborist, Facilities Services, Oregon State University, Corvallis, OR

Executive Summary

Public lands within the Urban Growth Boundary of Corvallis, Oregon contain a diverse population of about 440,000 trees that include over 300 varieties and have an estimated tree cover of 31%. While often unrecognized, urban trees provide a variety of "ecosystem services" or direct environmental benefits for people. This study used computer models developed by the USDA Forest Service to quantify these ecosystem benefits in both physical and economic terms. The annual benefits include:

- energy savings and avoided air pollutant emissions due to shading of buildings
- sequestration (storage) of carbon dioxide, the principal atmospheric greenhouse gas
- absorption of air pollutants
- reduction in stormwater runoff and required infrastructure
- increases in private real estate market values

The annual benefits were estimated at $4,000,000, which corresponds to an average of $9 per tree and $75 per capita. In terms of fixed asset values, the total amount of carbon dioxide stored was valued at $1.45 million and the total replacement value of the trees was estimated at $450 million. Enumeration of these benefits can raise citizen awareness of the value of their public tree resources, as well as provide a basis for management to maximize benefits while controlling costs.

Introduction

Trees in urban areas provide a number of benefits to the public. Besides their aesthetic appeal, they provide a number of tangible environmental benefits that often go unrecognized. In recent years, there has been increased research on quantification of "ecosystem services", the direct benefits that natural system provide to people (Millennium Ecosystem Assessment 2005). Enumeration of these benefits can raise citizen awareness of the value of their public resources, such as urban trees on publicly owned lands, as well as provide a basis for management to maximize benefits while controlling costs.

Fig. 1 is an illustration of some of the ecosystem services that urban trees provide. Building cooling costs can be decreased as a result of shading by trees. Not only does this represent a savings of energy, but it also avoids emission of air pollutants and greenhouse gases associated with producing that energy (McPherson and Simpson 1999). Trees improve air quality in other ways as well. They reduce air pollutants such as ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulate matter less than 10 microns in size (PM_{10}) by uptake of gases and interception of airborne particles (Nowak et al. 2006). While trees emit some volatile organic compounds (VOCs, an ingredient in ozone formation) themselves (Chameides et al. 1988), shading of parking lots reduces VOC emissions from asphalt and parked cars (Scott et al. 1999). Tree shade also increases the longevity of pavement (McPherson and Muchnick 2005). Growing trees sequester (store) carbon dioxide (CO_2), the primary atmospheric greenhouse gas (Nowak and Crane 2002). Impervious surfaces in urban areas generate runoff after storms that must be dealt with by stormwater drainage and treatment systems; trees intercept precipitation and reduce this stormwater runoff and the infrastructure costs associated with it (Maco and McPherson 2003). Finally, because of their aesthetic appeal and microclimate effects, the presence of trees increases private real estate market values (Anderson and Cordell 1988; Maco and McPherson 2003).

In recent years, several computer models have been developed by the USDA Forest Service and collaborators to assist cities in assessing the value and environmental benefits of their tree resources (www.itreetools.org). The models provide estimates not only of the physical benefits, but their economic value as well. The purpose of this study was to use these models to assess the ecosystem services provided by publicly owned trees in the Corvallis, Oregon urban area.

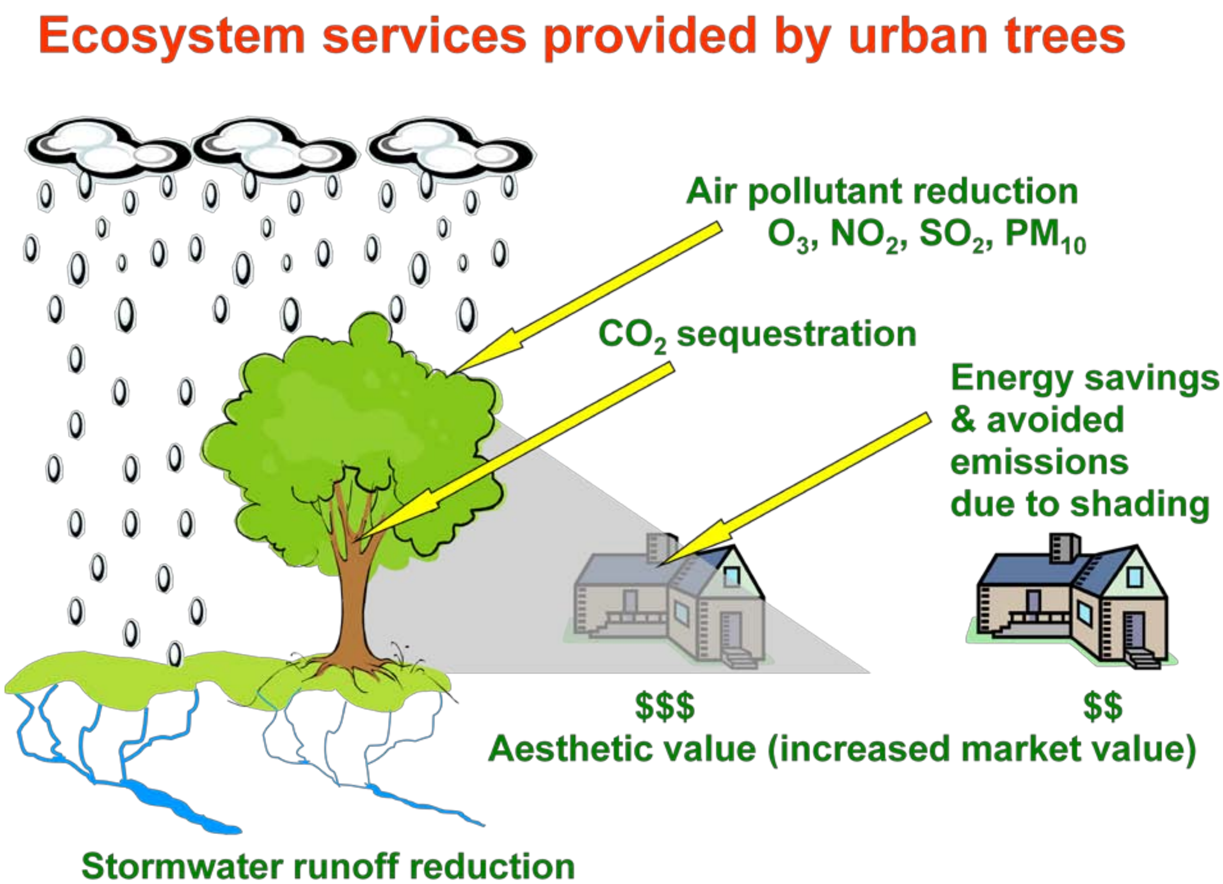

Fig. 1 – Illustration of ecosystem services provided by urban trees.

Methods

Study Area

In order to include benefits in the broader urban area, not just the city limits, the study area was defined by the Urban Growth Boundary (UGB). Due to access limitations for private property and a desire to focus on public resources, only publicly owned lands within the Urban Growth Boundary were considered. This includes all lands owned by state (e.g., Oregon State University, Board of Higher Education, Department of Transportation), county, and city institutions (e.g., City of Corvallis, Corvallis School District 509J). The total area of these public lands was 5369 acres, although 1348 acres around the Corvallis Municipal Airport was not considered because of the lack of trees. Based on the sample and inventory data, this study area has an estimated tree cover of 31%.

Data

Three sources of data on public trees were used in this study. The City of Corvallis Parks & Recreation Department maintains an inventory of city street trees (Figs. 2, 3a). The copy of the data base provided on April 16, 2009 had 13,252 complete tree records with valid species identification and diameter at breast height (DBH, at 4.5 foot height) values. Similarly, Oregon State University (OSU) maintains an inventory of trees on the main campus. The copy of the data base provided on April 16, 2009 contained 4,319 complete tree records (Figs. 2, 3b). These two data bases represent trees along streets on the OSU campus and elsewhere in the city, however parks and other public areas are not included. To represent these areas, 97 plots were randomly located within all public lands inside the Urban Growth Boundary, excluding the OSU main campus that was already covered by a complete inventory, and the area surrounding the Corvallis Municipal Airport that did not contain trees. The total area available for sampling was 3605 acres. At each randomly located point, a 0.1 acre circular plot was established (Figs. 2, 3c). The predominant land use and an estimate of the percent tree cover were recorded. For each tree in the plot, the following measurements were taken: DBH, crown diameter in north-south and east-west directions, height to live top, height to dead top (if applicable), height to the base of the tree crown, percent of the canopy missing, and crown light exposure (number of sides of the tree exposed to sunlight from above, including the top of the tree as a fifth side). For trees greater than 20 feet tall, the distance and direction to the nearest building within 60 feet was intended to be measured as well, but no buildings were encountered. Any street trees already covered in the City inventory were excluded.

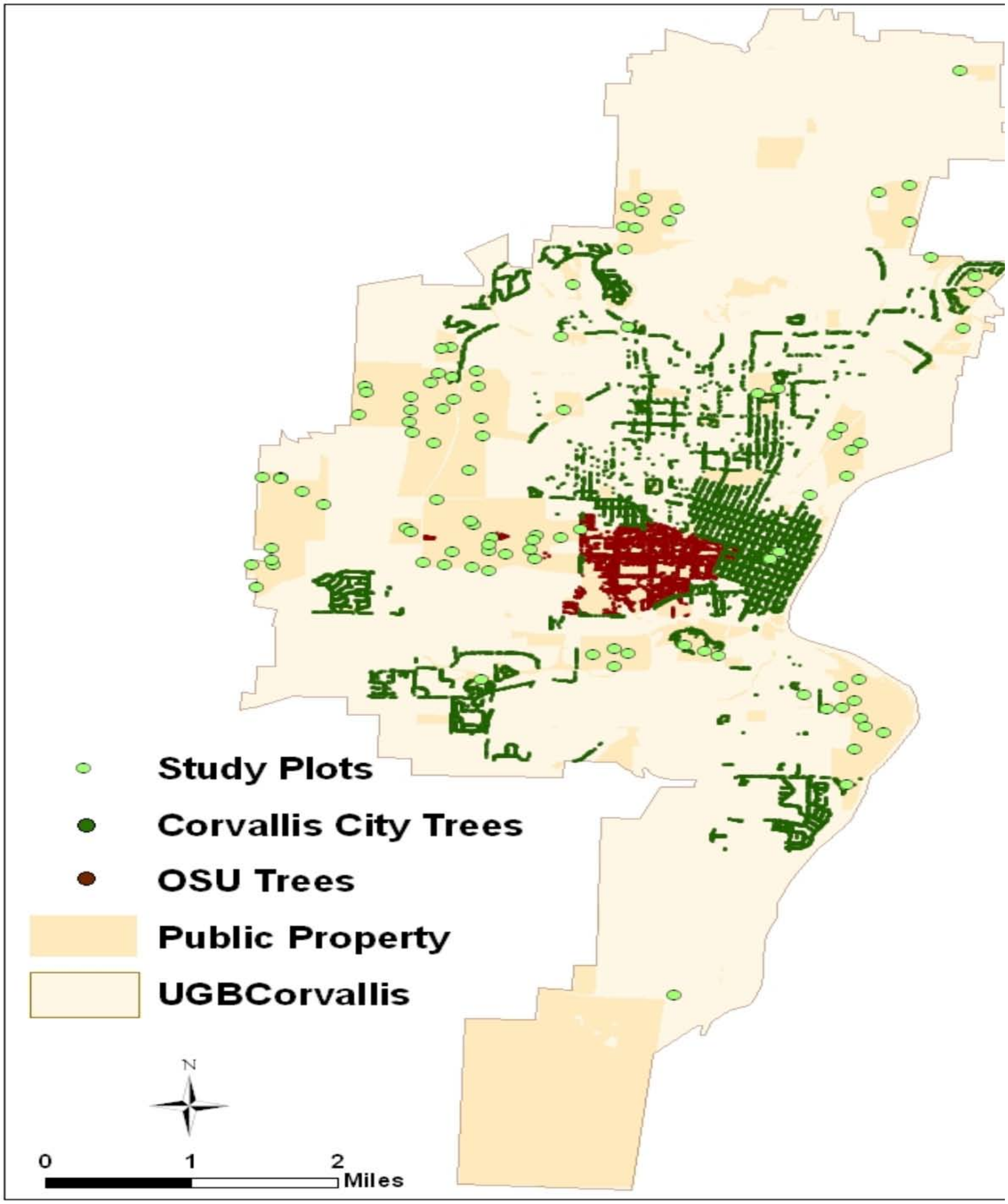

Fig. 2 – Locations of trees included in the City of Corvallis and OSU inventories, and of 97 sample plots randomly placed in public lands in the Corvallis UGB (excluding the Corvallis Municipal Airport and the OSU main campus).

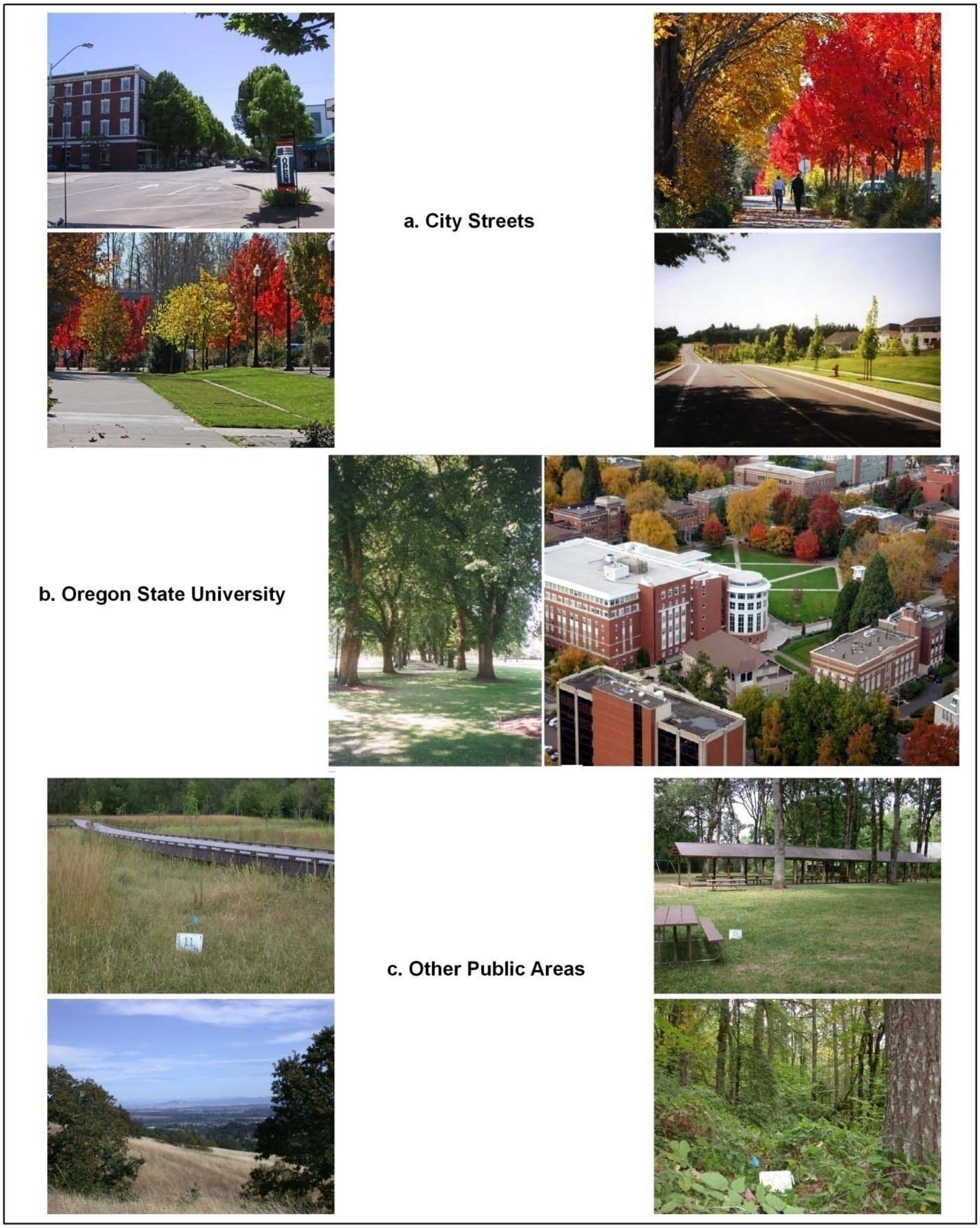

Fig. 3 – Photos of: a) City street trees; b) Oregon State University street trees; and c) sample plots in other public areas in the Urban Growth Boundary.

Models

The USDA Forest Service, along with collaborators, has developed a suite of software called i-Tree to provide urban forestry analysis and benefits assessment tools (www.itreetools.org). These models take individual tree data (for trees > 1 inch DBH) from complete inventories and/or samples, and estimate ecosystem services that the trees provide annually, including:

- Energy savings for cooling due to shading of buildings (energy units, economic value in $ based on energy costs). For monetary values, the electricity rate used was $0.0939 per kilowatt-hour [KWH] (equivalent to $26.08 per gigajoule [GJ]), based on the average Oregon residential rate for February 2011 from the U.S. Energy Information Administration (www.eia.gov/cneaf/electricity/epm/table5_6_a.html). The natural gas rate used was $1.1756 per therm (equivalent to $11.14 per gigajoule), based on Northwest Natural Gas Company's rate for Oregon effective June 1, 2011 (www.nwnatural.com/uploadedFiles/Schedule%202.pdf).
- Sequestration (storage) of carbon from atmospheric carbon dioxide (CO_2), a greenhouse gas (mass units, economic value in $ based on CO_2 emission control costs). CO_2 sequestration is determined from allometric equations based on tree species, diameter, and crown light exposure (Nowak et al. 2008). The monetary value used for CO_2 carbon was $0.0033 per pound ($20.30 per metric ton or megagram [Mg]), based on the estimated social costs for CO_2 emission for 2001-2010 (Fankhauser 1994; Nowak et al. 2008).
- Removal of air pollutants [nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matter < 10 microns in diameter (PM_{10})] (mass units, economic value in $ based on pollution control costs), including avoided emissions due to energy savings. The monetary value of pollution removal by trees is based on the median externality values for the United States for each pollutant, updated to 2007 values based on the Producer's Price Index (Nowak et al. 2008).
- Stormwater runoff reduction (water volume, economic value of stormwater management infrastructure savings in $). The models take into account the seasonal variation in leaf area for evergreen vs. deciduous trees, and calculate precipitation interception on an

hourly basis from local weather records. The monetary value used was $0.02779 per gallon based on cost studies in western Washington (McPherson et al. 2002).

- Aesthetics (as determined by annual increase in private real estate values based on tree presence, size, and growth). The median home sales price of $237,000 for Corvallis for May-July 2011 (www.trulia.com/real_estate/Corvallis-Oregon) was used as the basis for this monetary value calculation.

In addition to these annual benefits, the models also estimate one-time asset values of:

- total CO_2 sequestered (economic value in $ based on CO_2 emission control costs)
- replacement value (full cost in $ to replace a tree with a tree of similar species, size, and condition; based on Council of Tree & Landscape Appraisers Guide for Plant Appraisal)

One of these models, i-Tree Streets, was designed for assessment of ecosystem services provided by street trees and was used for analyzing the City and OSU tree inventory data sets. The model is not GIS-based, but works with basic inventory data on tree species and diameter. The model uses data bases and analyses performed in an intensively studied Reference City within the same i-Tree Streets Climate Zone (http://www.itreetools.org/streets/resources/Streets_Reference_Cities_Science_Update_Nov2011.pdf) for quantifying other aspects of tree structure (e.g., height, crown diameter, tree condition) and relationships of the tree data to ecosystem services and their economic values. The climate zone for Corvallis is Pacific Northwest, and the reference city is Longview, WA (McPherson 2010). However, as described above, electricity, gas, and real estate values specific to Corvallis were used rather than the default values for the reference city. We assumed that the same proportion of buildings were air-conditioned in Corvallis as in the reference city, and thus that the calculations for energy savings for cooling due to shading were appropriately scaled. The model is described in more detail in Maco and McPherson (2003) and the i-Tree Streets User's Manual (USDA Forest Service 2011b).

The other model, i-Tree Eco, was designed for assessment of entire forest tree populations across an urban area rather than linear features like street trees adjacent to roads. This model was used to analyze the sample plot data, which excluded the areas already covered by the city and OSU street tree inventories that were assessed using i-Tree Streets. The i-Tree

Eco model requires more extensive data collection for each tree as described above for plot sampling, rather than the basic species and diameter measurements used for i-Tree Streets with other data derived from a Reference City data base. More detailed descriptions of i-Tree Eco are available in Nowak et al. (2008) and the i-Tree Eco User's Manual (USDA Forest Service 2011a).

Collectively, the City and OSU inventories represent street trees on public rights of way and the OSU main campus, while the random plot samples represent trees in parks and other public areas within the UGB. Consequently, the ecosystem service assessments from the two i-Tree Streets model runs for the street tree inventories and the i-Tree Eco model run for the other public areas (scaled up from the plot data) were summed for a comprehensive assessment for all public lands in the UGB. The two models estimate the same ecosystem services, although some were not pertinent to all three data sets:

- Energy savings – This estimate was not used for the sample plot data because no nearby buildings were encountered that would be shaded by the trees in the plots.
- CO_2 sequestration (annual and total) – The two models differed in the prices used to determine the economic value of carbon sequestered. For consistency, the i-Tree Eco value of $20.30 per metric ton was applied to the results of all three model runs.
- Removal of air pollutants – For the i-Tree Eco run, this estimate only includes removal by tree foliage. Because no nearby buildings were encountered in the plot sampling, avoided pollutant emissions from energy savings were not included.
- Stormwater runoff reduction – The i-Tree Eco model does not estimate stormwater runoff volume reduction and its infrastructural cost savings as i-Tree Streets does. However, the City of Portland recently did a similar assessment of public street trees using STRATUM [i-Tree Streets] and park trees using UFORE [i-Tree Eco] (Portland Parks & Recreation 2007). For stormwater runoff reduction estimates for park trees, they also ran the CITYgreen model (American Forests 2004) which is similar to i-Tree Eco but does address stormwater endpoints. Their estimated annual stormwater reduction was 226 gallons per tree (0.856 cubic meters per tree). The DBH distribution of Portland parks trees (57% < 6" DBH) was similar to that of the Corvallis sample plots (60% < 6" DBH), the climate is similar (mean annual precipitation of 43.67 inches for Corvallis and 43.11

inches for Portland; http://usclimatedata.com), and they have similar topographic settings along the Willamette River, so this annual rate of stormwater reduction per tree was applied. A valuation of $7.34 per cubic meter ($0.02779 per gallon) in reduced infrastructure costs was applied to stormwater runoff reductions from all three data sets, as this was the value used both in i-Tree Streets and in the CITYgreen analyses done by the City of Portland (Portland Parks & Recreation 2007).

- Aesthetics – Since this component is based on increases in private real estate value from the presence of trees, it was only applied to the City street tree inventory because most OSU and sample plot trees are not adjacent to private property.

All model results are estimates and include uncertainties associated with parameter values and random variation among samples. Results are rounded to reflect the appropriate degree of precision in these estimates. The sample size of 97 plots was estimated to give a standard error of 17% for the i-Tree Eco results on "other public lands" (USDA Forest Service 2011a). As a rule of thumb, results were rounded to decimal units roughly reflecting a precision of one-third of the standard error. For example, for an estimate of $393,936, one-third of the standard error would be 1/3 x 0.17 x $393,936 = $22,323. Consequently, the estimate would be rounded to the nearest $10,000 and presented as $390,000. Because the "other public lands" component was by far the largest and the most uncertain due to random sampling rather than complete inventories, this rule of thumb was applied for presenting all individual model results and totals across model runs.

Results

There was a diverse array of trees among the three data sets including over 300 species and variety of trees. The most frequent diameter class for the City inventory and sample plots from other public areas was 3-6" DBH; the OSU trees were larger and more mature, with the most frequent diameter class being 6-12" DBH (Fig. 4). Based on the sampled plots, there are approximately 420,000 trees in UGB public lands in addition to the 13,252 and 4,319 in the City and OSU street tree inventories, for a total of about 440,000 trees (Table 1). Broadleaf deciduous trees and coniferous evergreen trees represented 82% and 18% of this population, respectively. These trees store a total of about 71,000 metric tons (1 metric ton = 1000 kilograms = 2205 pounds) of carbon from CO_2, which represents the equivalent of decreasing the greenhouse gas CO_2 in the atmosphere by ~262,000 metric tons. The economic value of this carbon sequestration is nearly $1.5 million (Table 1). The replacement cost for all these trees was estimated as ~$450 million (Table 1).

In addition to fixed asset values, the models also estimated annual benefits that public trees provide by way of a number of ecosystem services. Table 2 summarizes these benefits in biophysical units such as amount of energy saved, mass of pollutant reductions, and volume of stormwater runoff reduction. Fig. 5 summarizes the economic valuation of these annual benefits in dollars per year.

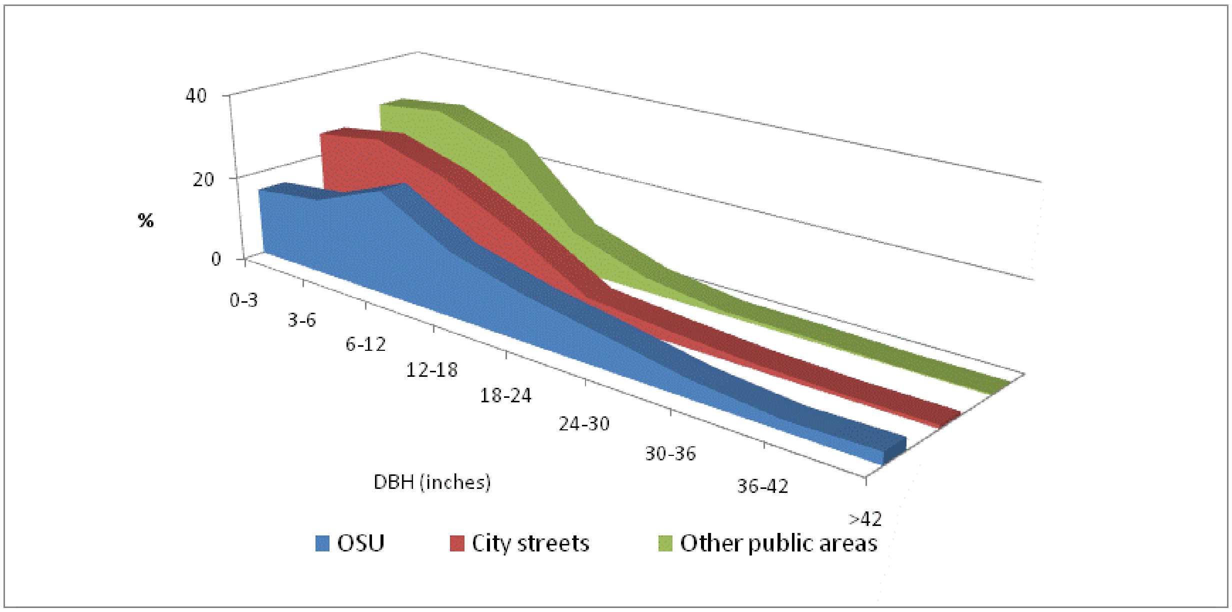

Fig. 4 – Diameter at breast height (DBH) distribution of OSU and City street tree inventories and trees sampled from other public areas.

Asset	City street trees	OSU street trees	Other public land trees	Total
# trees	13,252	4,319	420,000	440,000
carbon stored	$250,000	$170,000	$1,030,000	$1,450,000
replacement cost	$36 million	$24 million	$390 million	$450 million

Table 1 – Number of trees and fixed asset values estimated for public trees in the Corvallis UGB.

Annual benefits	Units	City street trees	OSU street trees	Other public land trees	Total
energy savings	GJ/yr	2,500	1,400	0	3,900
net carbon sequestration	Mg/yr	1,080	600	1,070	2,750
air pollutant reduction					
NO_2	Mg/yr	4.8	2.7	8.4	15.9
O_3	Mg/yr	0.9	0.6	19.5	21.0
PM_{10}	Mg/yr	0.6	0.4	23.2	24.2
SO_2	Mg/yr	0.8	0.4	2.1	3.3
stormwater runoff reduction	m^3/yr	29,000	18,000	360,000	410,000
aesthetic (private realty)	$/yr	647,000	0	0	647,000

Table 2 – Annual ecosystem service benefits in the Corvallis UGB. GJ = gigajoule = 1 billion joules = 278 kilowatt-hours. Mg = megagram = 1 million grams = 2205 pounds. m^3 = cubic meter = 264 gallons.

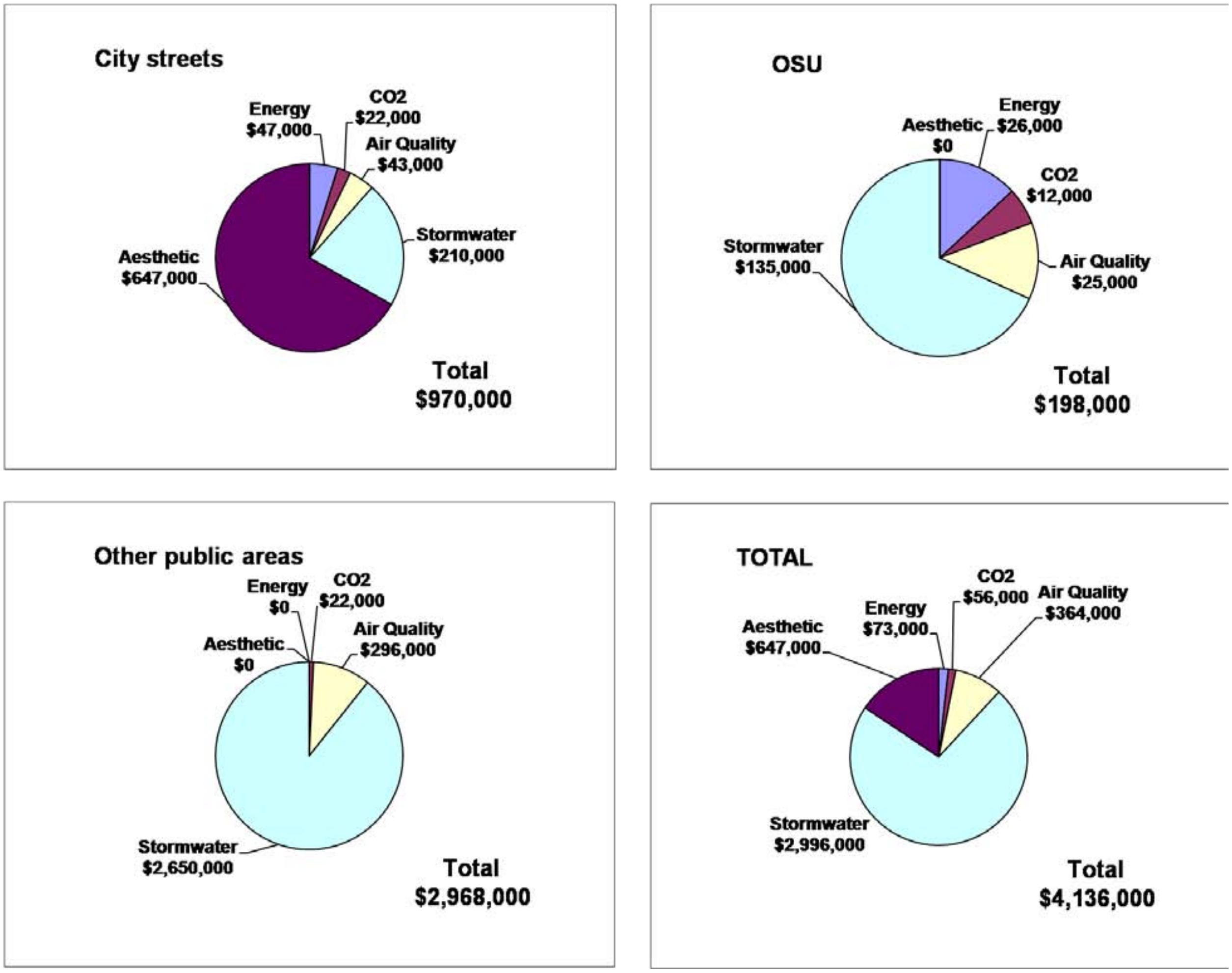

Fig. 5 – Economic valuation of annual ecosystem service benefits from public trees in the Corvallis UGB.

Discussion

The largest benefit varied among the data sets. The City street trees were the only ones for which an evaluation of increases in private real estate market values was done because the other trees were not immediately adjacent to private property for the most part. This effect on real estate values due to the presence and growth of trees was the largest annual benefit for the City street trees, estimated at $647,000, or $49 per tree. This contributed to City street trees having the highest annual benefit of $73 per tree. While the presence and growth of trees on the OSU campus and in other public lands does undoubtedly increase the value of those lands in some way on an annual basis, these areas are not in the real estate market and the measurement of tree effects on market values (Anderson and Cordell 1988; Maco and McPherson 2003) is not strictly applicable. While these annual incremental values were not quantified for this reason, the replacement value of trees on the OSU campus and other public lands was still considered in the evaluation of fixed asset values.

Savings due to infrastructural costs from reduced stormwater runoff was the largest benefit for the OSU trees and other public land trees. The largest single benefit was a $2,700,000 estimate for stormwater management cost reductions for other public lands, which was 90% of the total $3,000,000 stormwater reduction estimate. This is approximately the size of the capital project and annual operating budget for Corvallis stormwater services (http://www.ci.corvallis.or.us/downloads/fin/FY%2010-11/Proposed_FY10_11_Budget_Document/Proposed_FY_10_11_Budget_Document.pdf). This estimate, which is equivalent to $6 per tree, is based on the City of Portland park trees study and CITYgreen model analysis (Portland Parks & Recreation 2007). In developed urban areas there is a large proportion of impervious surfaces (e.g., pavement, rooftops) that prevent infiltration of precipitation and generate stormwater runoff. For both the Portland and Corvallis study areas, outlying natural areas within the UGB as well as central urban area were included, thus reducing the proportion of impervious surfaces. Thus the model estimates may reflect more a comparison of current runoff with many trees and natural areas compared to a more fully developed urban area.

Annual ecosystem service benefits ranged from $73 per tree for the 13,000+ City street trees, to $46 per tree for the 4,000+ trees on the OSU main campus, to $7 per tree for the 420,000 trees on other public lands. Overall, this averaged out to $9 per tree for the approximately 440,000 trees in public areas of the Corvallis UGB. Based on the 2010 census figure of 54,462 for Corvallis, the annual benefits come to $75 per capita.

While urban trees provide a number of benefits, there are also financial costs associated with them. Table 3 shows various costs that were reported by the city for 2010 and by OSU for average annual costs over the last 5 years. These include planting, pruning (including utility line clearance), management and monitoring operations, leaf removal, and the value of volunteer time. Other potential costs that were not reported might include sidewalk damage from tree roots, cleanup costs from storm damage, and others.

Cost category	City	OSU	Total
Planting	$18,970	$11,122	$30,092
Urban tree management	$159,308		$159,308
Utility line clearance (Pacific Power)	$435,700		$435,700
Pruning	$36,700	$36,906	$73,606
Removals	$44,447		$44,447
Volunteer time	$11,609		$11,609
Leaf pickup & disposal	$171,860	$19,887	$191,747
Dutch elm disease monitoring & pruning		$7,951	$7,951
TOTAL	$878,594	$75,866	$954,460

Table 3 – Annual tree-associated costs reported by the city (for 2010) and OSU (average of previous 5 years).

Conclusion

Corvallis's urban trees are a diverse and valuable part of the city's infrastructure. Although the benefits of urban trees are often unrecognized, they provide a number of valuable ecosystem services for the public, as enumerated here. Quantifying these services can help provide a basis for sound urban forest management and minimizing cost to benefit ratios, as well as providing citizens a better sense of the value of the natural resources where they live.

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