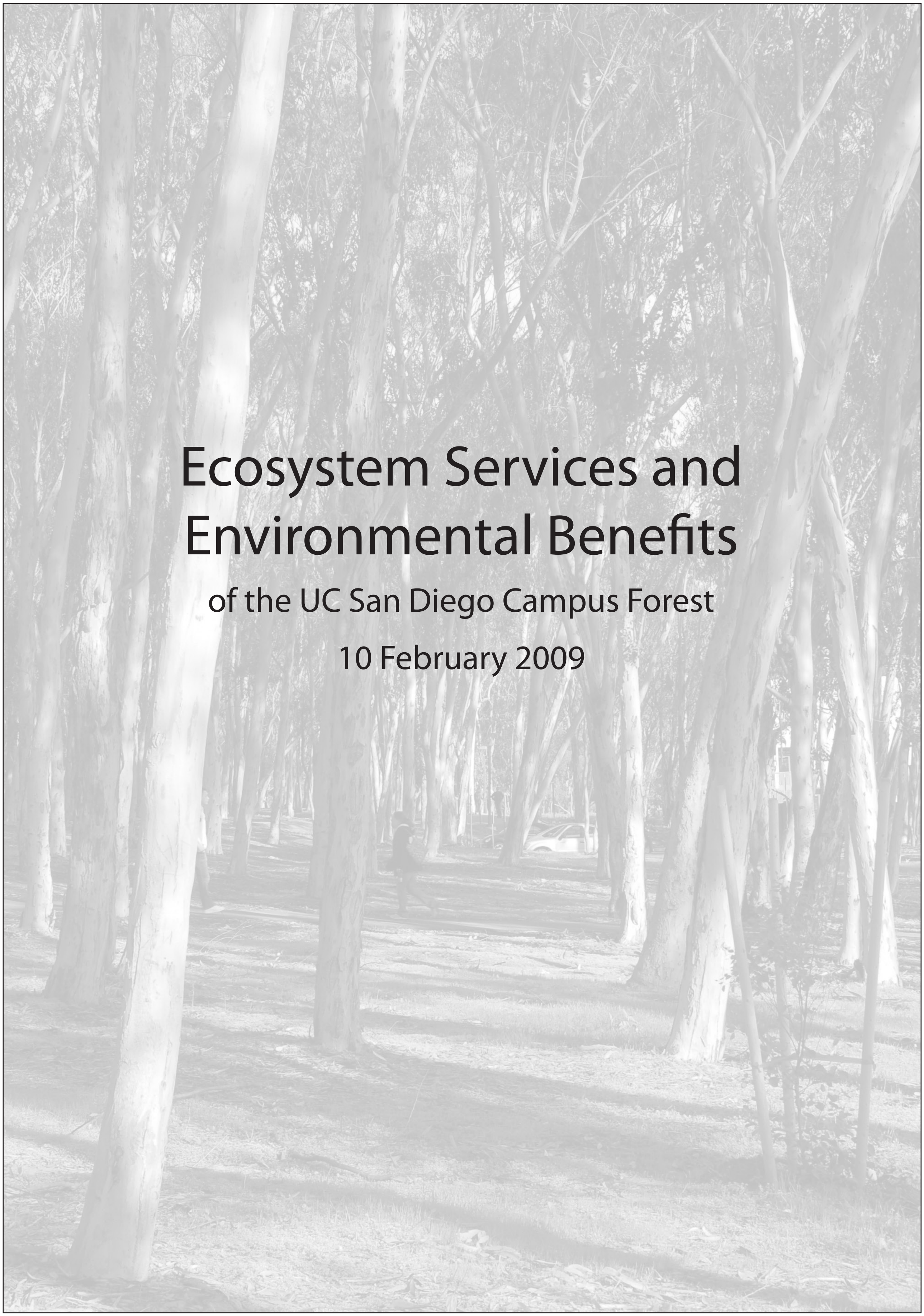

Ecosystem Services and Environmental Benefits

of the UC San Diego Campus Forest

10 February 2009

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Report to

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Acknowledgements

This study would not have been possible without the gracious help of several members of the UC San Diego staff. Sam Oludunfe, the campus urban forester, in particular, was very generous with his time and knowledge. As well, his UCSD Urban Forest Management Plan provided invaluable background information on the campus forest. Chuck Morgan, Assistant Director Building & Landscape Services, answered all my questions and took time out of his busy schedule to show me the campus and forest. Michelle Perez, Facilities Management Operational Sustainability Analyst, was available any time I needed data and helped me connect with the necessary people. Finally, Valerie Fanning, Compliance Officer, worked to track down some elusive information.

Executive Summary

The campus forest of the University of California, San Diego (UCSD), is a rich and varied ecosystem stretching from the Pacific Ocean across canyons and mesas. Many of the forest's benefits are well recognized. The trees serve as a reminder of the campus's cultural legacy and create a sense of place, a *genius loci*. They provide shelter and food for the flora and fauna that make their home there and create a more attractive environment for the people who live, work, and study at UCSD.

But urban and campus forests also have a valuable role to play in increasing the sustainability of our built environments. The great contributions of the ecosystem services that the trees provide—sequestering carbon dioxide, filtering water, reducing energy use, and cleaning the air—are often overlooked. This study works to quantify these ecosystem services in numerical terms using the latest models and research and then translate those numbers into dollar values.

UCSD's campus forest includes more than 200,000 trees. The majority are planted in the 112-acre eucalyptus grove that runs the length of the campus. The remainder comprise a broad mix of 100 species planted along streets and around buildings.

By consuming solar energy in the process of evapotranspiration and blocking winter winds, the trees of UCSD help reduce energy use by 12,886 MWh, valued at approximately $1.5 million. Through direct shade, the trees provide even greater energy conservation benefits. Without a complete inventory of the forest and information on tree location in relation to buildings, however, these benefits could not be calculated.

As trees reduce energy use, they reduce the amount of carbon dioxide (CO_2) produced at the power plant. As they grow they also sequester CO_2 from the atmosphere. Together, these climate change benefits result in a reduction in CO_2 of nearly 10,000 metric tons per year. This represents about 5% of UCSD's annual emissions, valued at $450,000/year. The total amount of CO_2 stored in the existing forest is 166,000 metric tons.

UCSD is working to alter its stormwater management program and stop untreated stormwater and dry-weather runoff from entering the ocean. Trees can contribute significantly to improving water quality and reducing runoff. The existing campus forest traps and filters nearly 140 million gallons of stormwater each year, with a value of $250,000.

Most of San Diego County, including the campus, remains on the EPA's list of areas that do not meet federal ozone standards. In addition, small particulate matter exceeds federal limits on a number of days each year. Through interception and absorption, the campus trees remove 73 tons of air pollutants, with an estimated value of $1.8 million. Trees can also have a negative impact on air quality as some species (eucalyptus are particular offenders) produce one of the precursors to smog. When this is factored in, the air quality benefit is estimated to be $500,000 with a net 5.2-ton reduction in air pollutants. Trees also have an indirect impact on air quality by helping conserve energy and thereby reducing emissions at the power plant.

As noted above, without a complete inventory of the forest and information on tree location in relation to buildings, these benefits could not be calculated.

The total value of these ecosystem services provided by the campus forest is $2.7 million each year.

Summary table of ecosystem services provided annually by the UC San Diego campus forest

Ecosystem service	**Annual volume**	**Total dollars**
Energy conservation	12,866 MWh	1,500,000
Carbon dioxide reduction	10,000 metric tons	450,000
Stormwater runoff reduction	140 million gallons	250,000
Air pollutant reduction	5.2 tons	500,000
Total		2,700,000

The campus forest offers many other environmental benefits that are less easily quantified. When planted to shade parked cars, trees reduce evaporative emissions that contribute significantly to poor air quality. In a study in Sacramento, it was estimated that increasing citywide parking lot shade to 50% (as required by city ordinance) would reduce evaporative emissions by several tons a day. Tree shade also helps protect pavement by reducing wear and tear on asphalt. A Modesto study estimated that unshaded streets required more than twice as many repavings over a 30-year period than shaded streets. Finally, the trees of the UCSD forest are the lifeblood of the diverse ecosystem they support. The forest is home to more than 100 species of birds, small mammals and other plants, and serves as an overwintering site for the majestic monarch butterfly.

The ecosystem services and environmental benefits as well as the cultural and aesthetic value of the existing campus forest are significant. There are a number of other ways that the forest can contribute to UCSD's pursuit of sustainability in the future. Strategic planting to combat the urban heat island effect and to reduce energy consumption through direct shade, tree planting projects to sequester carbon, the use of tree waste material for wood products or as biomass for power production, and maximization of the tree-soil complex to improve hydrology are just a few and are described in greater detail here.

Introduction

The University of California, San Diego's ecosystem is a rich and varied place, occupying 1,200 acres of coastal woodland stretching from the Pacific Ocean down into canyons and up into mesas. The campus forest, composed of more than 200,000 trees of 137 species, is the lifeblood of the ecosystem, providing food and shelter for the flora and fauna that make their home within it and creating a better environment for the 50,000 students, faculty, and staff who work and live there.

The 112-acre eucalyptus grove that winds it way from one end of the campus to the other is the heart of the campus forest with great cultural and historical value that extends even beyond its ecological value. Planted many decades ago in a failed attempt to provide timber to the burgeoning railway industry, the grove has stood watch over a changing landscape from wilderness to military rifle range to world-renowned university. The eucalyptus trees are a defining element of UCSD, providing the campus with a unique and beautiful character, and although the trees are clearly not a part of the native landscape, they nevertheless have a significant environmental contribution. The goal of this project is to better understand the contribution that the eucalyptus grove and the rest of the campus forest are providing.

Many studies assess the environmental value of an ecosystem *qualitatively*, listing the animals and plants found there and describing the network of systems—water, air, nutrients—that provide the underlying function. This study instead works to assess the campus forest's value *quantitatively*, calculating the air quality, hydrology, climate change, and energy conservation benefits of the campus forest numerically and then assigning a dollar value to those benefits where possible.

The eucalyptus grove

Species, size, and growth stage

To assess the environmental benefits of an urban forest, it is necessary to know the trees' species, size, and growth stage (growing vs. mature/stable). An inventory of the UCSD campus forest has not yet been conducted; therefore the necessary data were estimated based on historic records summarized in the UCSD Urban Forest Management Plan (Oludunfe 2008), the experience of the Building and Landscape Services staff (S. Oludunfe and C. Morgan, pers. comm.), and a visual assessment conducted by the author. A full or even sample inventory of the urban forest would provide more exact results and is highly recommended.

It is conservatively estimated that there are approximately 200,000 trees on campus. The vast majority (~90%) are eucalyptus species ranging in size from volunteer seedlings and newly planted 1-inch diameter at breast height (dbh) trees to mature specimens more than 3 ft in diameter. The remaining 10% of the population comprises more than 100 other species (Oludunfe 2008).

The eucalyptus trees have a varied history that is reflected in their growth. Most were planted in a 112-acre grove 45–70 years ago on an 8-ft grid (Oludunfe 2008). The tightness of the planting (and thereby the reduced access to water, light, and nutrients) has restricted growth such that the trees inside the grove are believed to have reached a mature, stable dbh of approximately 12–18 inches. Trees along the grove's perimeter and in well-irrigated areas are larger (dbh 18–36 inches), and because a eucalyptus with sufficient nutrients can easily grow to 50 or even 75 inches in dbh (Roxburgh et al. 2006), the largest trees are assumed to still be growing. In some areas, new trees have been planted as replacements and volunteer saplings have sprouted.

The eucalyptus trees can therefore be grouped into three size/growth categories: (1) small, growing trees (~15%); (2) large, growing trees (~15%); (3) medium, mature/stable trees (~70%).

The non-eucalyptus trees (~10%) include species of all sizes, conifers, broadleaf evergreens, deciduous trees, and palms. Because, however, they make up only a small fraction of the population, for the purposes of this assessment, it is sufficient to categorize them as (1) small, medium, or large and (2) broadleaf or coniferous. In the absence of more exact information, the remaining 10% are divided evenly among these six classes.

In a final step for calculation purposes, an "average" dbh was assigned to each class to represent the whole. Small trees were assigned a dbh of 4 inches, medium 15 inches, and large 24 inches.

New eucalyptus plantings among older trees

Ecosystem services and environmental benefits

Energy conservation

Introduction

Reducing energy consumption is perhaps the most critical component in the fight against global climate change, especially in areas where energy is derived primarily from fossil fuels, as is the case at UCSD (86% natural gas and 6% coal; Perez pers. comm., APS Energy Services 2007). Strategies that allow us to conserve energy as we search for alternative technologies are extremely valuable. Trees are one of those strategies.

Trees moderate building energy consumption in three ways: (1) direct cooling effect: by shading air-conditioned buildings and paved surfaces, trees reduce the amount of heat built surfaces absorb, (2) indirect cooling effect: during the evapotranspiration process, trees cool the air by expending solar energy that would otherwise result in heating the air, and (3) windspeed reduction: by slowing or blocking cold winter winds, trees help reduce heat loss through air exchange between indoors and out.

Shading and evapotranspiration are also the mechanisms by which trees help reduce the urban heat island effect, which occurs when built surfaces (roofs, roads, parking lots) absorb solar radiation and release it as heat. Cities can be as much as 9° F warmer than the surrounding undeveloped areas (Akbari et al. 1992). A recent study of New York City's urban heat island by scientists at NASA and Columbia University described street trees as the having the "greatest cooling potential per unit area."

Methods

A complete estimate of the environmental benefits of UCSD's urban forest would account for all three components of energy conservation. Direct shading effects and the effects of windspeed reduction on heating energy use, however, can only be calculated if complete information on tree location in relation to buildings is available. In the absence of a forest inventory, only the indirect climate effects due to evapotranspiration can be determined.

Energy conservation was calculated using the CTCC software tool developed by the US Forest Service Center for Urban Forest Research (CUFR) and accepted for use by the California Climate Action Registry (CCAR) as a means of estimating energy reduction from tree shading and climate effects.

The CTCC calculates energy conservation for the 20 most common species in six California regions. The first important step in using the tool is to match each studied species with the

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[1]The CUFR Tree Carbon Calculator (CTCC) is available at the US Forest Service's Climate Change Resource Center website (http://www.fs.fed.us/ccrc/topics/urban-forests/). More information on the development and use of the CTCC can be found in Appendix D of the Urban Forest Project Reporting Protocol (CCAR 2008).

most appropriate species (in terms of taxonomy, life form) in the CTCC. For this study, species were matched as follows:

Study species (or category)	CTCC species
Eucalyptus spp.	*Eucalyptus ficifolia*
Broadleaf	*Ficus benjamina*
Conifer	*Pinus canariensis*

Each representative species in each of the three representative sizes was then entered into the CTCC.

The dollar value of energy conserved was calculated based on the price that UCSD pays for purchased energy of $0.11796/kWh, which includes commodity and transmission charges (Dilliott and Peele pers. comm.).

Results

The campus forest of UCSD is estimated to reduce energy use through indirect climate modification by 12,866 MWh each year or approximately $1.5 million annually. Individual tree values ranged from less than 10 kWh/year for the smallest trees to more than 150 kWh/year for the largest broadleaf tree.

It is important to note that this is a conservative estimate of the energy savings due to trees as it does not include direct shading effects. If the relative location of the trees to conditioned buildings were known, the calculated energy savings would be much greater. Consider, for example, that the indirect climate effect of a large eucalyptus is estimated at 87 kWh/year. The same tree planted near the west side of a building is estimated to conserve 276 kWh/year—more than three times as much as the climate benefit alone.

Trees have the "greatest cooling potential per unit area" for reducing the urban heat island effect

Carbon benefits

Introduction

Trees work to reduce atmospheric carbon dioxide (CO_2) levels in two ways. First, as described above, they help conserve energy by moderating temperatures and they thereby reduce GHG produced at the power plant. Second, they sequester CO_2 from the atmosphere and transform it into living matter—leaves, branches, trunks, and roots. In fact, trees are the only viable existing "technology" for removing already high levels of CO_2 from the air.

Methods

The values estimated above for energy conserved were multiplied by the UCSD CO_2 emissions factor to calculate the reduced CO_2 emissions. Emissions factors (measured as kilograms of CO_2 per megawatt-hour of electricity produced) reflect the fuel mix used to produce energy. According to UCSD's 2007 annual report to CCAR, approximately 93% of the energy reported came from the campus's natural gas plant (emissions factor = 181 kg CO_2/MWh) and 7% was purchased from off-campus (California average emissions factor of 400 kg CO_2/MWh) (CCAR 2008). Averaging these two values proportionately to the percentage of electricity produced resulted in an average campus emissions factor of 196 kg CO_2/MWh.

Annual carbon sequestration and total carbon storage were estimated using the CTCC as described above with one adjustment made to its reported results. As noted in the section "Species, size, and growth stage," despite their small size (~15 inch dbh) relative to their potential, the eucalyptus planted within the grove are restricted in growth because of the tightness of the planting grid and are believed to have reached their maximum diameter (C. Morgan and S. Oludunfe, pers. comm.). To provide a conservative estimate of sequestration benefits by the campus forest, these are therefore assumed to have stopped growing and thus to have stopped sequestering carbon. For these trees, a value for total carbon storage is provided but not for annual sequestration.

Placing a dollar value on carbon benefits is not straightforward. The market in the United States for trading carbon offsets is in its infancy and even the more established European market fluctuates wildly from $0/metric tonne (t) after over-allocation of emission credits to a recent high of 27.54 EUR/t last summer (Phillips 2008); the current price is 13.25 EUR/t. Attempts to price the social cost of carbon are even more wide ranging, with one meta-analysis of 88 estimates presenting a mode of $5/t, a mean of $104, and a 95th percentile of $446 (Tol 2005). For this study, Tol's median value for peer-reviewed studies ($47) is used.

Results

Emission reductions due to conserved energy for the UCSD campus are estimated to be 2,500 t CO_2. Annual sequestration by the campus forest is estimated to be 7,250 t CO_2. Together this represents about 5% of UCSD's annual emissions (192,000 t; CCAR 2008), valued at $450,000/year. As noted above in the energy conservation section, this should be seen as a conservative estimate because the reduced emissions include only indirect climate effects and not direct shading benefits, which can be several times greater.

The total carbon dioxide stored in the trees is 166,000 t, with an estimated value of $7.8 million.

Trees reduce atmospheric carbon dioxide levels by sequestering carbon and by reducing energy use

Stormwater benefits

Introduction

Nonpoint-source pollution (polluted runoff from diffuse sources) is one of the most significant causes of contamination in our waterways and much of the damage comes from runoff from our streets and chemically treated lawns and gardens (US EPA 2007). Currently all stormwater run-off on the UCSD campus is channeled into storm drains and flows directly without treatment into the ocean. New regulations address this problem and new solutions are being considered. Trees should be seen as a valuable part of the solution.

Trees capture rainwater and remove impurities, reduce volume into sewer systems, and reduce peak stream flows. Canopy cover helps reduce erosion by reducing the impact of raindrops on bare ground. The soil the trees are planted in should also be considered a critical part of any hydrological system as it can store and filter even greater amounts of both rain-water and dry-weather runoff.

Methods

Stormwater benefits were estimated using CUFR's software tool i-Tree STRATUM (i-Tree 2009). The three representative species in the three representative sizes were run through STRATUM's hydrology model. The results were multiplied by the approximate numbers of trees in each of the species/size classes. STRATUM results are regionally based; the Southern California Coast region was selected.

STRATUM also estimates a dollar value for the hydrology benefit; in the absence of more exact information the default value for the region was used ($0.00183/gal; for information on how this value was derived, see McPherson et al. 2000).

Results

UCSD's urban forest was estimated to trap and filter nearly 140 million gallons of stormwater each year, valued at $254,000 annually. Average per-tree values ranged from 100 gallons for the small eucalyptus to 2,200 gallons for the large conifer.

Air quality benefits

Introduction

Although the air quality in San Diego is better than much of the surrounding area, work remains to be done. Most of San Diego County including the UCSD campus remains on the US EPA's 8-hour ozone nonattainment list (US EPA 2008). The American Lung Association has also graded the city with an "F" for ozone levels and an "F" for maximum 24-hour levels of small particulate matter (PM_{10}), although the annual grade for PM_{10} is a "pass."

Trees can help clean the city and campus air in several ways. They absorb or intercept air pollutants, they reduce energy use by lowering temperatures and thereby reduce the production of pollutants at power plants, and they shade parked cars, reducing evaporative emissions. At the same time, trees can sometimes have a potential negative effect on air quality by producing biogenic volatile organic compounds (BVOCs), a precursor to ozone.

Methods

Air quality benefits in terms of nitrogen oxides (NOx), sulfur dioxide (SO_2), ozone (O_3), volatile organic compounds (VOCs) and PM_{10} were calculated using CUFR's STRATUM program as described above for hydrology. STRATUM calculates air quality benefits that derive from two sources: (1) interception and deposition on leaves and bark and (2) avoided emissions at the power plant resulting from direct and indirect energy conservation. Because it is not possible to distinguish between the direct and indirect energy conservation benefits in STRATUM and we lack information to allow us to determine the direct energy benefit, only the deposition benefits are calculated here.

Research into the complex interactions among BVOCs produced by trees, air temperatures, and smog is lacking, but to provide the most conservative estimate of benefits, the potential contribution of BVOCs to air pollution is accounted for in STRATUM.

Prices were assigned to air pollutants in several ways. For pollutants traded on the market as emission reduction credits for the San Diego Air Pollution Control District, the most recent bid price was used (Cantor Fitzgerald 2009). These were $30,000 per tons per year (tpy) for NOx and $20,000/tpy for VOCs. Prices for NOx and VOCs were used for O_3 and BVOCs, respectively (McPherson et al. 2000). The U.S. price for allowances for 2009 was used for SO_2 emissions: $150/tpy. In the absence of a relevant market for PM_{10}, control-based costs reflecting population and maximum concentrations (US EPA 2008) were used (Wang and Santini 1995): $12,820/tpy.

Results

UCSD's campus forest is estimated to intercept 73 tons of air pollutants each year, valued at $1.8 million. Once the BVOC emissions are accounted for, the net positive impact on air quality from the trees due to interception is $500,000 and the net reduction is 5.2 tons. Values differed according to tree size and species. The smallest trees intercepted the least amount of pollutants (0.06 lb/year); the large broadleaf trees intercepted the most ($1.2 lb/year). BVOC emissions differ by species and size as well. Eucalyptus are among the worst emitters. Here the large eucalyptus emitted more than 10 lb/year; other species have zero emissions.

Other benefits

Trees provide a number of other environmental benefits that are less easily quantified but are nevertheless valuable.

Evaporative emissions

It is well known that vehicle emissions are one of the main causes of air pollution, but what is less familiar and somewhat surprising is the role vehicles play when they are not running. Evaporative emissions of VOCs from parked cars through leaky fuel tanks and worn hoses contribute significantly—as much as 16%—to smog (Scott et al. 1999).

Trees have a valuable contribution to make in reducing these emissions. By shading asphalt and parked cars, trees reduce the temperature of both the atmosphere and the vehicle itself, reducing evaporation. A study in Davis, CA, found that fuel tank temperatures in shaded parked cars were as much as 7°F cooler than unshaded cars and their interiors were nearly 30°F cooler (Scott et al. 1999). These lower temperatures translate to reduced emissions.

The study also modeled the effects of increasing parking lot shade for Sacramento County. The city of Sacramento has a parking-lot shade ordinance that requires 50% shade 15 years after development. Compliance is almost never achieved, and it is estimated that the current level of cover in parking lots is approximately 8%. According to the study model, if Sacramento's parking lots were brought into compliance with the regulations, emissions would drop by approximately 2.2 tons (Scott et al. 1999). Although modest, this reduction is similar to those anticipated by other funded measures of the air quality district (e.g., reductions from the graphic arts industry, waste burning, energy efficient appliances).

Asphalt protection

Public works engineers often decry the damage that trees do to paving without considering their beneficial impact on asphalt performance. Higher pavement temperatures increase volatilization of asphalt binder, which loosens the aggregate. The loose aggregate acts like sandpaper, grinding away the pavement. By reducing the surface temperature, tree shade reduces binder volatilization.

A recent study comparing repair records for shaded streets versus unshaded streets in Modesto, CA, found that the shaded blocks required fewer than half as many repavings over a 30-year period (2.5 vs 6.0; McPherson and Muchnick 2005). The well-shaded street in the study was estimated to reduce repaving costs by $0.66/ft^2 over the 30-year period.

Habitat

Urban settings are not the barren, natureless places they are sometimes imagined to be. In fact, because of their variety of ecological niches, developed areas can sometimes support more species of flora and fauna than the surrounding, native conditions, and the transition zone where the city meets areas of open space is often home to the greatest species diversity (Zerbe 2002). Urban trees can serve a valuable role in the ecosystem by providing habitat for local fauna and corridors for movement between natural areas.

UCSD's very diverse campus forest, with an estimated 137 tree species, supports a broad array of plants and animals, including many small mammals and birds of prey (Oludunfe 2008). The San Diego Natural History Museum's Bird Atlas lists 122 species of birds found on or near the UCSD campus, including several species of hummingbirds and hawks, osprey, and peregrine falcons (SDNHM 2009a). The Museum's Mammal Atlas has not been completed, but will likely include voles and moles, bats, jackrabbits, and perhaps mule deer, coyotes, and fox (SDNHM 2009b). In addition, the grove serves as a valuable overwintering site for monarch butterflies (Oludunfe 2008) after their long journey from the north.

The campus forest is the lifeblood of the ecosystem that supports these animals, providing shelter and food. Because the grove runs as a corridor through the length of the campus, it also potentially allows for movement of animals (and plants over the long term) between the parks to the north of campus (Torrey Pines State Reserve, Los Penasquitas Canyon Preserve) and those to the south (Soledad Natural Park, Rose Canyon Open Space).

A well-shaded parking lot reduces evaporative emissions, improving air quality

Future opportunities

In this document, we have concentrated on the environmental benefits that the existing UCSD campus forest is providing, including carbon sequestration, air quality improvement, stormwater management, and energy conservation. There are a number of other ways, however, the forest could contribute to UCSD's pursuit of sustainability in the future. Strategic planting to combat the urban heat island effect and to reduce energy consumption through direct shade, tree planting projects to sequester carbon, the use of tree waste material for wood products or as biomass for power production, and the use of the tree-soil complex as a mini-reservoir to improve hydrology are just a few.[1]

Tree planting projects

The CCAR has recently added a protocol to allow urban forest tree planting projects to be registered for carbon offsets, and university campuses are one of the eligible entities. In short, this would require the campus to first achieve the performance standard of replacing each tree that is removed each year. Once the performance standard has been met, additional trees are eligible to serve as offsets.

The procedure for reporting projects is not simple. It requires monitoring, replacement of dead trees, and annual reporting for 100 years. Nevertheless, if trees will be planted for other reasons, such as to reduce energy consumption or to ameliorate the urban heat island effect, it may make sense to also pursue the advantages of registering the project with the CCAR. The offsets could be used against any deficiencies on campus or could be traded to other entities should a cap and trade market arise as is expected. The Chicago Climate Exchange (CCX) also offers a reporting mechanism for forest projects and makes brief mention of urban forestry.

Strategic planting

Future tree planting projects should specifically consider energy conservation and the urban heat island. For energy conservation through direct shading, focus planting efforts on the west and east sides of unshaded buildings. Leaving the south sides of buildings free of shade will reduce energy consumption in winter. Species characteristics such as mature size and deciduous vs. evergreen should be considered. Larger, wide-canopy species will provide more cover, potentially shading heat-absorbing roofs, sidewalks, and streets. Columnar and other narrow canopy forms should be avoided.

To lessen the urban heat island effect, concentrate on increasing canopy cover over paved and built surfaces. Parking lots are particularly valuable for tree planting because reducing

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[1]All of these strategies require more accurate information about the existing urban forest than is currently available. Strategic planting around buildings, for example, can not occur until the locations of existing trees are known. For this reason, an inventory of the urban forest is highly recommended. A stratified sample inventory of the eucalyptus grove and a full inventory of the other trees should be a first step. A full inventory of the grove could also be valuable to determine the locations of hazard trees that pose a safety risk or trees that are threatened by pests or disease.

Unshaded parking lots offer potential for tree planting, strategic cooling, and stormwater treatment

temperatures there helps reduce evaporative emissions and improve air quality. On campuses, parking is usually in great demand and administrators (and drivers) are reluctant to replace parking spaces with trees. CUFR's Fact Sheet #3: Making Parking Lots More Tree Friendly (CUFR 2002) offers some suggestions for resolving this conflict, including "Convert double-loaded full-size spaces to compact spaces with a tree in between to increase shade without reducing the number of spaces." Avoid species with messy or slippery fruit or those that are prone to attacks by pests that will leave vehicles and sidewalks covered with sticky exudates. Trees should be tolerant of hot, dry conditions, and in parking lots, strong branch attachments are critical.

Mini-stormwater reservoirs

As described above, the campus forest already plays a crucial role in managing stormwater runoff by trapping and filtering precipitation. With some planning, however, the trees' contribution can be greatly increased, especially near paved and built areas. Each tree together with the soil it is planted in can be designed as a mini-stormwater reservoir, and this tree-soil complex can store and filter a great deal more stormwater and dry-weather runoff than the tree alone, particularly if an engineered soil is used as planting material.

Scientists at UC Davis and CUFR are researching a new design in which stormwater from a parking lot drains toward a swale planted with trees and filled with Davis soil, a mixture of 75% lava rock and 25% clay-loam soil. The swale provides a growing medium for trees and shrubs and a storage area for runoff, while the soil itself helps trap pollutants as the runoff filters through it. The system is designed to capture all runoff from a 10-year storm (3.1 inches of precipitation) or 97% of all rainfall events. In initial laboratory results, the Davis soil removed 47–99% of nutrients and 75–96% of heavy metals from the runoff (for more information, see CUFR 2007).

Using similar designs, the UCSD campus forest can capture and treat stormwater and runoff naturally before it ever reaches the ocean.

Biomass and wood products

Currently on the UCSD campus, pruned material and dead trees are chipped for use as mulch (Morgan, pers. comm.). If, in the future, the amount of material should exceed the campus's mulch requirements, tree waste could be considered for use as biomass feedstock in biopower plants. Research is also underway to develop efficient ways to convert wood into fuels such as ethanol, bio-oil, and syngas, but these methods are not yet ready for widespread commercial application (Zerbe 2006).

Wood products are another potential use for tree waste and a particularly valuable one from a climate change perspective because as wood decomposes (such as occurs rapidly with mulch), it returns the sequestered carbon back to the atmosphere. Durable wood products, however, retain the carbon for as long as the products last (even centuries for some construction lumber or fine furniture). Some cities, such as Sacramento and Lompoc, are working to create a market for urban wood to construct fences, benches, tables, and other furniture. For more information, visit the Urban Forest Ecosystems Institute's Urban Wood webpage (http://www.ufei.org/urbanwood/index.html), sponsored by CalFIRE. CCAR is also preparing a protocol to address the use of wood products to store carbon.

There has been some concern that a market for tree waste, either in the form of bioenergy or wood products, risks creating a perverse incentive to cut down trees. In urban or campus situations such as on the campus of UCSD, this is very unlikely; the economics of urban forests simply do not support such a concern. Unlike in a nonurban forest where trees are mostly left to grow on their own, a significant amount of money is invested to plant, water, prune, and treat urban trees. The return from selling tree waste for wood products or bioenergy is unlikely to ever exceed the cost of growing and maintaining the trees in the first place or of harvesting them in challenging urban environments. Additionally, residents, students and university staff often develop an attachment to their forest that precludes the possibility of large-scale removal. For these reasons, mechanisms to avoid this risk were not even considered necessary in CCAR's Urban Forest Protocol.

Nevertheless, if concerns remain, stricter language could be added to the UCSD Urban Forest Management Plan (Oludunfe 2008), perhaps indicating that trees can not be removed solely for the purpose of selling their wood or biomass.

Conclusion

Many of the benefits of UCSD's campus forest are known. The trees serve as a reminder of the campus's cultural legacy and create a sense of place, a genius loci. They provide shelter and food for the many animals and plants that make their home there and create a more attractive environment for humans.

What may be less well understood is the enormous role trees play in increasing the sustainability of our built environments through the significant ecosystem services they provide. The urban forest helps clean the air, filter water, reduce energy use, and work in the fight against climate change by removing carbon dioxide from the air. The total value of these services is estimated at $2.7 million each year.

As UCSD strives to reach its sustainability goals, the campus forest can play an increasing role. Strategically planting trees to maximize energy conservation and reduce the urban heat island effect, making use of soil the trees are planted in to increase hydrology benefits, increasing canopy level to increase carbon sequestration, and finding uses for wood after trees have been removed will provide significant return on investment, all while making the campus a more beautiful place to be.

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