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Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns

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Abstract Tree planting programs are being implemented in many US cities (most notably New York, Los Angeles, and Chicago) on the basis of the multiple environmental and health benefits they may provide. However, the magnitude and even the direction of the impacts of trees on specific urban environments have seldom been directly measured. In addition, there has been little research on the historical, cultural, political or institutional origins of such programs, or on their implementation process. Pending questions include the degree to which these programs are integrated in the existing frameworks of city government and infrastructure management, how they are paid for, and the kinds of collaborations between nonprofit organizations, the public, and public agencies at all levels they may require in order to succeed. This paper reports on an interdisciplinary research project examining the Million Tree Program of the City of Los Angeles.

Keywords Urban forestry · Ecosystem services · Implementation · Hedonic valuation · GIS, green infrastructure

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Tree planting programs are being implemented in many US cities for their multiple environmental and health benefits. These include reducing stormwater runoff; providing shading, which reduces the urban heat island; improving air quality by intercepting various pollutants; sequestering carbon; enhancing health by fostering walking and providing a connection with nature; and beautifying neighborhoods (McFarland 1994; Brack 2002; de Vries et al. 2003; Foster and Hillsdon 2004; McPherson et al. 2005, 2011a, b). However, the magnitude and even the direction of the impacts of urban trees on specific urban environments have seldom been directly measured. In addition, there has been little research on the historical, cultural, political or institutional origins of such programs, or on how to design them and implement them effectively.

In this context, this paper presents results of a research project conducted by an interdisciplinary team consisting of ecologists, economists, geographers, remote sensing experts and urban planners to examine some facets of the ecosystem services provided by urban trees in Los Angeles. More specifically, we examined the following questions:

1. What will be the impacts on water use in Los Angeles, which is located in a semi-arid climate and where water shortages may be exacerbated by climate change, of planting one million additional trees?
2. What is the carbon sequestration value of planting a million new trees?

3. Do trees in the public right of way in Los Angeles increase residential property values as alleged by proponents of tree planting?
4. Do trees in Los Angeles cool the urban environment?
5. What is the history of tree cover in the city?
6. How is a major new infrastructure program—planting a million trees—implemented in a time of acute fiscal austerity?

To address these questions, we adopted a coupled socio-ecological approach, where we strived to examine various relationships and interactions between human social systems (with a focus on urban tree planting programs) and ecological systems, using insights from ecology, economics, geography, planning, and remote sensing. Our goal was to better understand different facets of tree planting programs as part of complex social-ecological systems (SESs) (Ostrom 2009) where nature is managed to provide ecosystem services and enhance human welfare. In this paper, we use the term ecosystem services as defined in the Millennium Ecosystem Assessment (2005) to make explicit the link between human welfare and services provided by ecosystems. This definition provides a useful framework for our work by delineating different types of services (classified as supporting, regulating, provisioning and cultural) (Table 1).

Results we present herein attempt to quantify some of the impacts of the urban forest in Los Angeles specifically to evaluate whether the urban forest in this bioregion provides the ecosystem services that urban forests are claimed to bestow (a functional reason for planting more urban trees) or whether urban tree planting reflects a popular trend—or fashion. Los Angeles is among many cities across the country (including New York, Chicago, Denver and Sacramento, to name a few) where planting trees has been motivated by purported environmental benefits; at the global level, we should also mention the one billion tree planting campaign of the United Nations Environment Programme.

Table 1 Summary of the questions addressed and methods used in this study

Question	Methods
1. What is the water cost of the urban forest?	Direct measurements of tree water use
2. What is the carbon benefit of the urban forest?	Measurements of water use efficiency, comparisons between net primary productivity (NPP) and C emissions
3. Do trees increase property values?	Hedonic pricing analysis
4. Do trees provide a cooling benefit?	Analysis of remote sensing data
5. How has tree cover changed over time?	Analysis of historical photos
6. How was tree planting implemented?	Interviews, content analysis, historical analysis

We begin by reviewing the rise of interest in urban ecosystem services and tree planting in particular, and then turn to a historical overview of urban forestry and the forces that have contributed to the popularity of such programs in the United States. We then present the results of our research of the Los Angeles Million Tree Program and conclude with suggestions for further research.

The rise of ecosystem services programs

With growing concerns about environmental degradation and the increased concentration of the world's populations in cities, attention has turned to the ability of cities to mitigate their own impacts through various strategies, including the creation of infrastructure that provides ecosystem services (such as urban forests) or through low impact development standards (Benedict and McMahon 2006; EPA 2009; Lukes and Kloss 2008; Bitting and Kloss 2008; Bélanger 2009; ASLA 2010; CNT 2010; Rees and Wackernagel 1996).

Trees are often singled out for their urban benefits, which include (McFarland 1994): increasing property values; fostering economic development; reducing surface water runoff; conserving energy; improving air quality; reducing noise pollution; enhancing health; providing wildlife habitat; reducing runoff and erosion; providing a buffer between different land uses; and providing aesthetic benefits.

The importance of benefits from ecosystem services was pointed out by Daily (ed., 1997), and further elaborated in the United Nations Millennium Assessment report (2005). Classic works such as *Design with Nature* McHarg (1969), *The Granite Garden* (Spirn 1984), *Cities and Natural Process* (Hough 1995), provided the groundwork for considering cities as potential remediation sites and emphasized that natural processes continue to exist in cities. They also proposed cities take better advantage of these processes for cooling, recreation, biodiversity conservation, groundwater recharge and more.

In the twenty-first century, the potential value of urban ecosystem services for improving the urban environment has penetrated the popular literature and influenced people's imagination; tree-planting programs are an application of these ideas. Interestingly, little fundamental ecosystem science has taken place in cities to examine the veracity of these claims (Pataki et al. 2011b) and to quantify potential disamenities (Pincetl 2010a, b; Pataki et al. 2011b; Lyytimåki et al. 2008). Moreover there are significant costs to implementing and maintaining tree planting and other ecosystem services programs that are difficult to fund given decreased municipal budgets and conflicting urban regulations.

Why an urban forest? Some explanatory insights from history

City tree planting is a relatively new phenomenon. It emerged from the changes in cities that occurred with urban growth stimulated by the industrial revolution. With the terrible living conditions of the mid 1850s in the new industrial cities, access to public open space for health and recreation, including tree-lined public walkways, were part of a reform agenda in Britain that spread to other European countries. In the US American Fredrick Law Olmsted—who designed Central Park in New York City and a numbers of other urban parks in US cities—was strongly influenced by his experience of parks in England during this period (Lawrence 2006, pp. 188–189). Grand works were begun in the 1850 and 1860s. Lawrence writes about this period as a transition from the preindustrial city, where primary planning considerations were aesthetic and visual, to an industrial city whose primary planning considerations were providing efficient transportation, protecting public health, and maintaining the social order (Lawrence 2006; Pincetl and Gearin 2005). Lawrence points out that the parks and tree-lined streetscapes of the preindustrial city were adapted and multiplied throughout the urban fabric for their utilitarian value. At the same time, the preservation of forests outside of cities began for their urban water supply benefits. US Forests and watershed protection were seen as part of the urban environment, providing what we would call today ecosystem services: water regulation services as well as aesthetic and recreational attributes. In the Los Angeles area, for example, President Harrison in 1892–1893 set aside the mountains surrounding the basin for their watershed value.[1] In town, developers planted trees along with housing developments, because trees were associated with beautification. While the federal government was not directly involved in tree planting in urban areas in this early period, there was federal interest in the relationship between resource supply (such as water and timber) in or close to urban areas and the urban benefits of ecosystem function in the surrounding hinterlands.

In the US tree planting along residential streets took hold in the late 19th century. In 1872, J. Sterling Morton, former governor of Nebraska, a largely treeless state, founded Arbor Day as a national day of tree planting in towns and rural areas. This set a precedent for tree planting even in bioregions that were not naturally forested. Tree planting became a civic obsession. Citizen groups formed in many cities to organize the planting of street trees. Lawrence (2006) points out that early on tree-planting movements concentrated their efforts in the wealthier parts of towns, and they were sometimes resented by working-class residents who held that the money and efforts could be better spent dealing with more pressing issues such as public health, housing or education.

In European cities, trees were generally the responsibility of municipal authorities. Consistent with American values, in the US the emphasis was on volunteer efforts to plant trees in neighborhoods while city governments usually were responsible for trees only along large avenues or parkways (Lawrence 2006 pp. 247). Tree planting was therefore less consistent in

[1] Public lands in this period were being sold and/or provided to settlers to encourage economic development and settlement in the western US. While Yellowstone National Park had been created—carved out of the public domain to be preserved in perpetuity, as had Yosemite and a few other reserves—most of the land in the public domain was seen to be best utilized by private interests. The growing awareness of the relationship between urban water supply and forest management led President Harrison to begin to withdraw acreage from sale to ensure the preservation of forest ecosystem services.

the urban fabric than in Europe, despite concerns by landscape architects about planting inappropriate trees and aesthetic chaos.

Trees, as Cohen (2004) writes, have a particular and powerful hold on American conceptions of what is good in nature and the environment: "As we attempt to cope with environmental crises, we increasingly enlist trees as agents of our stewardship over nature" (page 1). Over the course of the early 20th century the conservation movement connected the late 19th century concerns about impacts of humans on forests (as expressed by John Perkins Marsh 1864 in his *Man and Nature*) and urban water supply (Stoll 2011). Gifford Pinchot, head of the Forest Service (FS) (1905–1910), believed that there was a moral obligation to take care of soils and forests. He enlisted Liberty Hyde Bailey to lead the Country Life Commission. Bailey pointed to the examples of the Puritan town and the country church in caring for trees, woods and vistas and the connection to parks and urban landscaping (ibid). Pinchot advocated planting and care for trees in urban settings for moral and environmental reasons.

Pinchot, understanding the need for support by constituencies for his forestry efforts and for the FS, quickly began to develop cooperative relations with lumber groups and regional interests. In the early twentieth century, agencies like the Forest Service were new, and represented a sea change in federal scope and responsibility. Pinchot realized the success of the FS depended on the agency providing services to constituents so they would support the agency's existence and growth. For example, in 1905 Pinchot went to the directors of the National Lumber Manufacturers Association to seek support for bureau programs and for forestry research. In exchange the FS offered federal outreach assistance to landowners, processors and consumers of forest products. This gave favorable public visibility to Forest Service officers (Robbins 1985). To this day, Pinchot's approach to cultivating stakeholders remains deeply entrenched in Forest Service programs and policies. With the rise of the environmental movement and greater attention to cities, by the mid 1970s formal federal Forest Service assistance became available for urban tree planting, modeled on the Forest Service's long tradition of cooperation in rural areas.

There would be much to learn about the specific history of links between Forest Service programs and city tree planting over the course of the twentieth century with increased attention to urban populations and the creation of forest recreational programs for them accompanied by outreach efforts. By the early 1960s federal interest in urban areas was undisguised. For example, the Forest Service, as well as the US Department of the Interior, were involved in the Outdoor Recreation Review Commission (ORRC) of 1964 that called for greater public access to the public lands and for the creation of more public lands in and around major metropolitan areas. The ORRC report paved the way for the establishment of the Golden Gate National Recreation Area, the Santa Monica Mountains National Recreation Area, and Fire Island National Seashore among others. It also established formal federal interest in using its resources to increase public recreational opportunities.

By the 1970s, another ORRC report had been written and influenced the 1978 Cooperative Forestry Assistance Act of Congress. The Act translated the benefits of tree planting into a law that directed the Forest Service to work in urban areas. An Urban and Community Forestry program was created under the State and Private Forestry Division of the Forest Service. Its Advisory Council continues to fund challenge grants to organizations involved in urban forestry. The Council's board of directors is directly appointed by the secretary of agriculture, according to a formula that mandates distribution of its seats among government, nongovernmental organizations, academia and business (Cohen 2004, p. 110).

The Forest Service Urban and Community Forestry Program, while a small part of the agency's Cooperative Forestry Program, is a direct result of congressional directions stating that the health of forests in urban areas and communities is in decline—reflecting the concerns of urban forest constituents and the Forest Service itself.

One of the older Forest Service nonprofit collaborations is Tree City USA. Tree City USA, which is one of National Arbor Day Foundation's programs, operates in conjunction with the US Forest Service and the National Association of State Foresters. It is partially funded by the FS and it is cosponsored by the US Conference of Mayors and the National League of Cities. The goal of this organization is to foster tree planting in urban areas, to develop programs that promote tree planting and to ensure maintenance of trees in perpetuity (Cohen 2004, p. 50).

A more recent example of the involvement of the Forest Service in urban forestry (2011) is the establishment of a national "Vibrant Cities" Taskforce that is expected to lobby Capitol Hill on the benefits of urban forests. Vibrant Cities is a collaboration of Plan NYC and the Forest Service and it has appointed 24 people from across the country to urge support for urban ecosystem services, most specifically trees.

The Forest Service, to support tree planting in cities, has monetized the value of trees through the development of tools to quantify urban forest values. For example, the Urban Forests Effects (UFORE) computer model, which was developed in the late 1990s, calculates the structure, environmental effects and values of urban forests (Nowak et al. 2003). It is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify numerous urban forest impacts, including tree effects on air pollution, greenhouse gases and global warming, and building energy use. This model has been widely distributed and utilized to estimate the value of the urban forest across the country. UFORE, for example, has quantified the value of total air pollution removal from the urban forest in California at $136,800,800 (http://nrs.fs.fed.us/data/urban/state/?state=CA, Accessed March 7, 2011). Another tool is I-Tree, available on line, which is a "state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban forestry analysis and benefits assessment tools" (http://www.itreetools.org/, accessed May 16, 2011). However, neither takes into consideration the costs of urban forests, such as irrigation, nor the tastes of local residents.

The Forest Service has also recently invested in an Urban Research Station in New York City that is deeply involved in supporting the New York Million Tree program and in assisting the growth of urban ecological stewardship. The creation of the Vibrant Cities Taskforce mentioned above, to advocate for urban forestry and urban ecosystems, further demonstrates the continuing involvement of the FS in urban areas.

As this discussion illustrates, interest in urban forests in the US has a long history, including support from the US Forest Service and from congress. Tree canopy cover is widely believed to bring important benefits to urban areas.

The million tree planting program of the city of Los Angeles

The Million Tree program of the city of Los Angeles offered an opportunity to study the ecosystem benefits and potential disamenities of a new urban tree planting program. We examined the potential water use impacts of a million more trees; the carbon sequestration value; the residential property value impacts of trees in public rights of way; their cooling effects and the implementation of the program. We also examined the evolution of tree planting in Los Angeles, a place that historically was not forested (Cunningham 2011; Bakker 1984) (Trees grew along riparian corridors and foothills where there was groundwater). We conducted archival research and historical reconstruction and mapping of the landscape using aerial photos, satellite imagery and GIS. Together, the components of the study provided a complex and interactive analysis of this program. Specific methods and findings are described below.

Forest service analysis

Given the long-standing concerted effort by the federal government and nonprofit organizations to encourage more urban tree planting, coupled with concerns about environmental degradation and greenhouse gas emissions, it is scarcely surprising that mayors of many cities have embraced urban forestry as a means of mitigating their city's environmental impacts and looked to the Forest Service for technical assistance. Two of the best-known urban forestry programs, Million Trees NYC and Million Trees Los Angeles, contracted with the Forest Service to analyze their existing tree canopy covers, the potential for planting a million more trees, the valuation of services from their existing urban forest, and the potential contribution of a million more trees for improving each city's environment and economy.

McPherson et al. (2007, 2011a, b) in a study conducted by the Pacific Southwest Research Station, US Forest Service Center, Center for Urban Forest Research (CUPR) analyzed the existing tree canopy cover (TCC) in Los Angeles using 2002–2005 data, including the distribution of TCC by Council District, and the potential for planting another million trees given the constraints of current land uses (Fig. 1). McPherson et al. (2007) found that: (1) the city's 2006

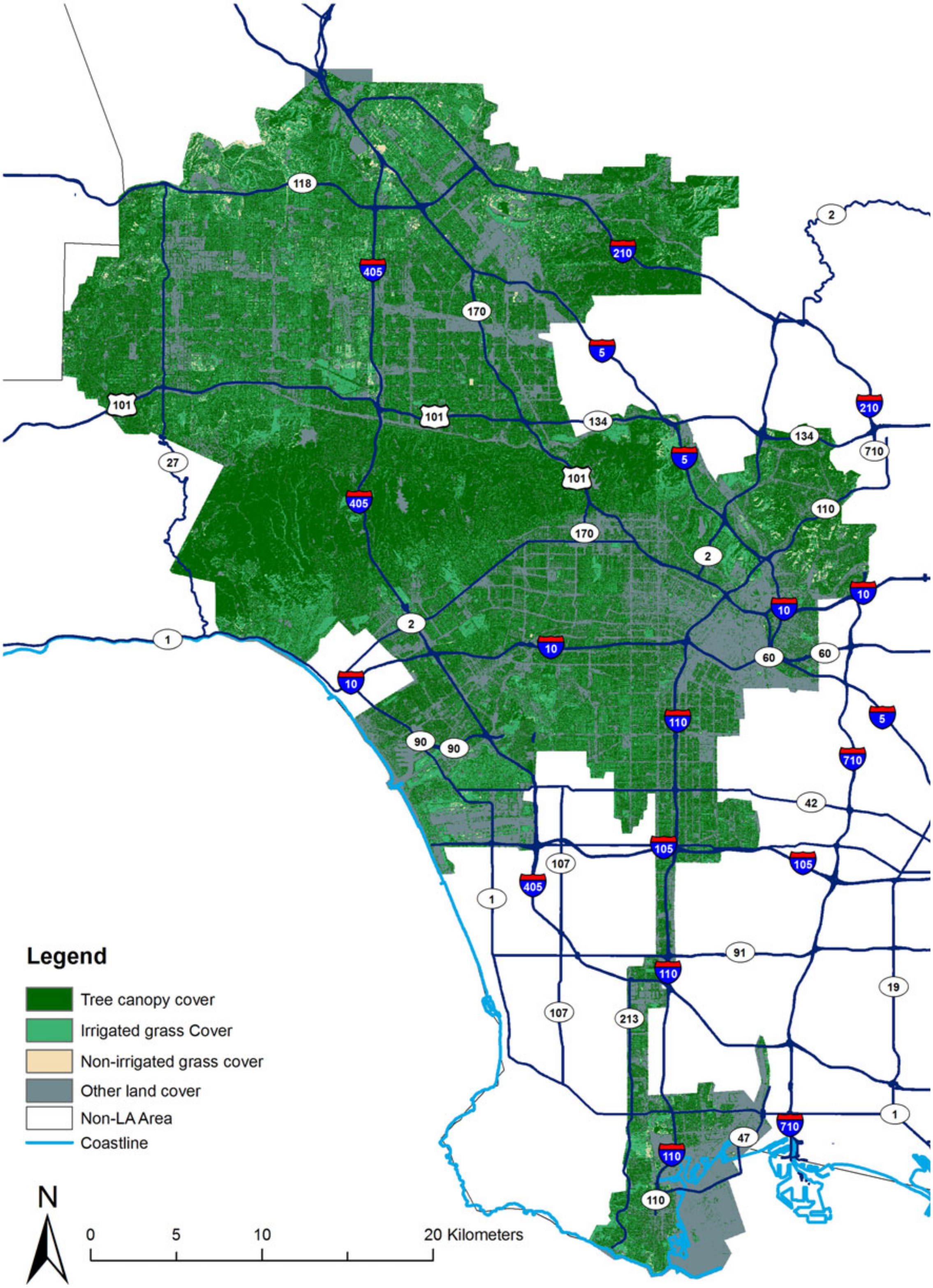

Fig. 1 Los Angeles Land Cover (McPherson et al. 2007)

TCC compared favorably to Baltimore (TCC of 20%) and New York (TCC of 23%) with an existing TCC of 21%, pointing to no lack of urban trees despite a semi-arid climate and lack of native forest cover, compared to other major metropolitan areas characterized by more rainfall and indigenous forests (2) there was room for planting a million more trees; and (3) tree canopy cover was distributed unequally across the city with poorer neighborhoods of color having fewer trees. Ranges of TCC varied from 7 to 37% in the different council districts. They also found that the greatest potential for tree planting was on private lands (McPherson et al. 2007). Furthermore, they estimated that planting 1-million more trees would yield up to $1.95 billion dollars (undiscounted) of benefit for the city over 35 years. It is important to note that most of these benefits (81%) were aesthetic, 8% were stormwater runoff reduction, 6% energy savings, 4% air quality improvement and less than 1% atmospheric CO_2 reduction. Moreover, McPherson et al. (2007) did not take into account the costs of planting and maintaining trees, (potential disamenity values), water use, nor any implementation issues. Nevertheless, it became the basis for going forward with the Los Angeles Million Tree planting initiatives.

Similar studies have been contracted for many cities across the country and show positive benefits for urban forests (Simpson and McPherson 2007; McPherson et al. 2011a, b for numerous studies). Let us now consider the issues of water use and carbon sequestration of urban trees.

Water use and carbon sequestration of urban trees

Los Angeles is located in a semi-arid, Mediterranean climate. Prior to urbanization, the region was dominated by coastal sage scrub and chaparral shrublands. Native forests in the Los Angeles area are limited to high elevation conifer forests, riparian corridors, or oak woodlands with adequate, deep soil moisture. In most locations of the Los Angeles basin annual rainfall, which is limited to winter and spring months, is inadequate to support forests (Schoenherr 1995; Rundel and Gustafson 2005).

Hence, planting and maintaining the Los Angeles urban forest generally requires irrigation, which creates a tradeoff between environmental costs—e.g. importing water from the over-allocated Colorado and Sacramento River watersheds, and benefits. However, prior to our study, there were few reported measurements of irrigated tree water use and growth for most of the species common in the Los Angeles urban forest, making it difficult to assess these tradeoffs.

To address this problem members of our research team monitored water use and growth of mature urban trees in locations throughout Los Angeles and the surrounding area using methodology described in McCarthy and Pataki (2010), Litvak et al. (2011), and Pataki et al. (2011a). It was estimated that for typical urban planting densities (100–200 trees per hectare), water loss could be as high as 1–2 mm d-1, or as low as 0.1–0.2 mm d-1 depending on the selection of species (Pataki et al. 2011a). Using this information, we estimated that the Los Angeles urban forest could consume up to $\sim$62% of municipal water use if composed entirely of high water using species, but may only consume $\sim$9% of municipal water use if composed of low transpiring species. The actual value depends on the current species composition; limited current inventories suggest that high water use species are common, though inventories for the entire municipal area are unavailable.

Since irrigation is an environmental cost, the tradeoff between water and carbon sequestration (growth) was assessed in a commonly used cost-benefit framework. This tradeoff between water lost in transpiration and carbon sequestered in growth is called Water Use Efficiency (WUE), and it varies by species depending on their origin (tree species in Los Angeles are imported from all over the world), location, and management.

Findings indicated that water use varies greatly across common species, by more than a factor of 10 (Fig. 2). Trees with low water use included Australian species such as *Populneus discolor* (lacebark), *Brachychiton populneus* (kurrajong) and *Eucalyptus grandis* (grand eucalyptus), as well as *Sequoia sempervirens* (coast redwood). Several common urban species such as *Ficus microcarpa* (laurel fig), *Platanus hybrida* (London planetree) and *Gleditsia triacanthos* (honeylocust) had high water use. Notably, *Platanus racemosa* (California sycamore), one of the few trees native to the Los Angeles area, was also found to have very high water use—largely because it is a riparian species.

In terms of tradeoffs between water and carbon, the most "efficient" trees at sequestering carbon per unit

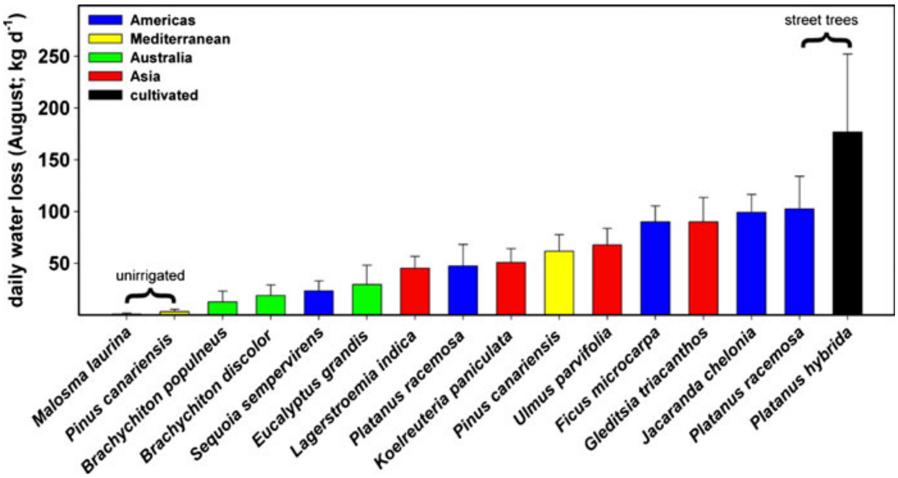

Fig. 2 Average daily tree transpiration in August estimated from direct measurements of sap flux in mature trees in Los Angeles. The legend indicates the region of origin or whether the species is a hybrid cultivar. Measurement methods and study locations are described in McCarthy and Pataki (2010), Litvak et al. (2011), and Pataki et al. (2011a, b)

water loss were *Eucalyptus grandis*, *Brachychiton populneus*, *Populneus discolor*, and *Ficus microcarpa* (McCarthy et al. 2011). On the other hand, some other common species in the urban forest including *Jacaranda chelonia* (jacaranda), *Gleditsia triacanthos*, *Koelreuteria paniculata* (golden rain tree), and *Lagerstroemia indica* (crape myrtle), were much less efficient and used relatively large amounts of water per unit carbon removed from the atmosphere. In general, the most water efficient species were evergreen, and from regions of the world which have low humidity and high air temperatures. These results suggest that there are multiple strategies for achieving high water use efficiency in urban trees, ranging from low water use and average growth to high water use and high growth. This means that low water use is not always coupled to low growth (and the other accompanying ecosystem services), and that trees with high water use efficiency may also have high water use.

The lessons for urban forestry programs are that species are highly variable in their environmental costs and benefits, and treating the urban forest as a homogenous entity can lead to gross errors in quantifying the net value of ecosystem services, such as the wide range of possible estimates of urban forest water use as function of species. In addition, previous assumptions about which species are efficient at providing services or that have high environmental costs such as water consumption are not borne out by our measurements (it is commonly assumed, for example, that native species will use less water than non-natives). These preliminary results suggest that lack of direct empirical data on urban tree ecosystem services is a limiting factor in assessing the impacts of urban tree planting programs. Moreover, total carbon sequestration by the urban forest cannot appreciably offset CO_2 emissions from urban fossil fuel combustion. Ngo and Pataki (2008) estimated total carbon emissions from the Los Angeles urbanized area as 21 kg C $m^{-2}year^{-1}$. In contrast, the upper limit on forest C sequestration expressed as Net Primary Productivity (NPP) would be about 1–2 kg C $m^{-2}year^{-1}$ if all of the urban area were forested (Saugier et al. 2001), which it is not. In reality, biological C sequestration is far lower than this in the urban area; NPP of the native grasslands and shrublands, for example, is estimated to range from 0.25 to 1.0 kg C $m^{-2}year^{-1}$ (Saugier et al. 2001); in addition, large portions of the urban area have been converted to paved and built structures. For trees to offset appreciable amounts of anthropogenic CO_2, forests would need to be planted in areas much larger than possible in Los Angeles. Hence, planting urban trees to reduce carbon emissions would accomplish little while requiring substantial imported water.

Estimating the value of urban trees

Understanding the net benefits of urban trees is critical to justify planting programs financed by public funds or simply to budget funds to maintain existing urban trees on public land. A couple of approaches are available to jointly estimate private and public benefits from urban trees.

The first one is the contingent valuation method (CVM), which surveys people for willingness to pay for changes in environmental quality based on hypothetical scenarios (Carson et al. 2001). This approach has been widely used for a number of natural amenities partly because it can capture existence value (i.e., the value that people place on knowing that an environmental good exist even if they have no intention of ever consuming it), and it has been applied a number of times to urban trees (see Tyrvainen 2001; Treiman and Gartner 2006; Vesely 2007). However, the CVM provides information about stated preferences, not actual behavior.

The second approach estimates the benefits and costs of the ecosystem services that trees provide (e.g., see McPherson et al. 2005; Nowak et al. 2007). While this is clearly useful for policy analysis, it requires detailed data on tree populations and community forestry expenditures that are often unavailable. Other important limitations that appear to have been overlooked in the urban forestry literature, is that this approach typically does not reflect the preferences of urban residents, nor water use as we discussed above.

Most published studies interested in the value of urban trees focus instead on private benefits of urban trees (esthetic qualities, air quality improvements, erosion reduction, and shading), which are likely to be capitalized in the housing market and have been found to capture the bulk of the value of urban trees (e.g., see McPherson et al. 2005, 2011a, b). Different approaches have been used to for estimating the impact of urban trees on the housing market. Early studies (Payne 1973; Morales et al. 1976) analyzed hand-picked datasets using ordinary least squares (OLS). An alternative is the travel cost method (Hotelling 1949), but with the exception of Dwyer et al. (1983), it has not been used for valuing urban trees because it is not thought to work well for neighborhood recreational resources (More et al. 1988). A review of the literature (see Saphores and Li 2012) suggests that the approach of choice to study the value of urban trees is the hedonic pricing method (Rosen 1974), which has been widely applied to study different environmental externalities (Sirmans et al. 2006). It has become more popular to study urban trees thanks to advances in remote sensing, geographic information systems (GIS), and econometrics (including spatial econometrics and geographically weighted regression models).

Our review of the literature revealed several research opportunities. First, most published papers of the benefits of urban trees in the United States focused on east coast ecosystems, and we found only two published papers that studied urban trees in a Mediterranean climate (Conway et al. 2010; McPherson et al. 2011a, b) characterizing Los Angeles and a number of developing megacities. McPherson et al. (2011a, b) suffer from several limitations: their estimated benefits are not discounted; over 80% of their reported benefits come from "aesthetic/other"; their quantification of benefits from additional trees does not account for the local density of existing trees (it is uniform across the city); and it ignores the tastes of local residents. Second, little appears to be known about the impact of green spaces, and urban trees in particular, on the value of multifamily buildings in large cities like Los Angeles (LA). This is a serious problem because LA residents of multifamily buildings are often disadvantaged economically, belong to minority groups and have less tree canopy cover than more affluent neighborhoods. Finally, a number of studies that estimate the benefits and costs of ecosystem services provided by trees (e.g., McPherson et al. 2005, 2011a, b) rely on results by Anderson and Cordell (1985, 1988) in their study of Athens, Georgia, although Anderson and Cordell cautioned about transferring their results to other ecosystems.

To address some of the questions above, we studied separately the Los Angeles market for single family detached houses (Saphores and Li 2012) and the multifamily building market (Li and Saphores 2011). First analyzed were 20,660 transactions of single family detached houses sold in Los Angeles in 2003 and 2004 using fine-grained hedonic models with many covariates to control for unobserved neighborhood characteristics. We found that Angelenos like trees but not so much on their parcels: additional parcel trees would decrease the value of almost 40% of the properties examined and they would have only a small positive impact on most of the others. By contrast, additional neighborhood trees would slightly increase the value of over 88% of the properties analyzed. This suggests that while Los Angeles residents may want additional trees, they are unwilling to pay for them.

Similar results were found in the analysis of 1,197 multifamily buildings sold in 2003–2004 (Li and Saphores 2011). Two models were considered (a spatial Durbin model and a geographically weighted regression model) to assess the robustness of our findings. Results indicated that increases in parcel tree canopy cover (TCC) will typically not increase the value of multifamily buildings; by contrast, most multifamily properties in the sample would benefit from an increase in TCC in their vicinity.

These results differ from those in most published studies, which report that more parcel trees would increase property values (e.g., see Donovan and Butry 2010, or Sander et al. 2010, and the references herein). They suggest that property values do not uniformly increase in all cities as a result of TCC. These findings also have implications for tree planting programs that rely heavily on private property owners, such as the Million Trees Los Angeles program (MTLA), where private property owners are expected to plant 70% of new trees. Indeed, not all residents will be willing to participate in tree planting in their neighborhoods, nor maintain the trees. Thus the "cultural" ecosystem value (MEA 2005), as estimated by monetary benefits from housing sales is not apparent in Los Angeles, while the costs of irrigation and maintenance (disamenities) are reflected in the lack of price advantage of housing with tree canopies.

Urban heat island and cooling effect of trees

Another important claim about trees in the urban environment is that they reduce the urban heat island (Akbari 2002). Urban heat island refers to the characteristic warming of urban areas compared to their rural surroundings as a result of changes of surface and atmospheric conditions from urbanization (e.g., expansion of buildings, roads, pollution, or energy use). Urban heat island is an inadvertent climate change that arises from changes to surface radiation and energy balance and reduction of cooling rates in urban areas. This effect is attributed to the large expansion of non-evaporative impervious material covering large urban areas which increases sensible heat flux and decreases latent heat flux (Voogt and Oke 2003). Urban heat island has significant implications for human comfort and health, urban air pollution, energy management, and urban planning. In cities located in hot climates, the urban heat island effect causes higher cooling loads and energy use with increased human discomfort. In temperate and cold climates, it may provide some benefits especially in winter by reducing heating loads (Akbari and Taha 1992; Akbari et al. 2001).

In Los Angeles, which is characterized by a semi-arid landscape, a warm climate, and topographically complex terrain, we found that urban shade trees offer significant potential benefits in reducing the demand for cooling and energy use. However, their impacts require a detailed understanding of the effect of trees in cooling surface temperatures, their spatial distribution along industrial and major transportation corridors, and across the urban landscape. It also requires energy billing data that can reveal whether neighborhoods with urban shade trees use less energy than equivalent neighborhoods with no shade trees.

We examined the effect of trees in cooling the surface temperature using a combination of satellite derived tree cover (McPherson et al. 2007), vegetation index, and surface temperature. Our goal was to quantify: (1) The relative impact of trees on reducing Urban heat island; (2) The relative impact of climate change and variability on the urban heat island; and (3) Changes of surface temperature resulting from changes in urbanization and in tree cover over the past 30 years.

We compiled satellite visible and thermal data from Landsat series and ASTER imagery over Los Angeles for the past 30 years and collected data from thermal bands for both day and night times at different dates to capture both diurnal and seasonal variations in heat distribution over the city. All satellite thermal bands were calibrated to represent land surface temperature (LST) using data from 16 meteorological stations distributed over the city. We then estimated a multivariate model using McPherson et al.'s (2007) tree cover data to quantify the impact of tree cover of tree cover on the urban heat island.

We found that the percentage of shaded tree cover in city blocks explains more than 60% of land surface temperature variations. Other factors, such as distance to the coast and topography, explain the rest of variations. City blocks with more than 30% tree cover can be about 5° cooler than areas with less than 1% trees. The ratio of impervious surfaces to trees was the main determinant of heat distribution over the city. Irrigated grass (lawn) had almost no impact on reducing the surface temperature, suggesting that tree shade is the major source of cooling compared to surface evapotranspiration from irrigated grass or trees (that is to say, irrigation does not contributes to cooling). The relative role of trees on cooling the surface varied during the year. The effect of shaded trees was larger during spring, summer and early fall and gradually reduced in winter when overall air temperature was cooler. Nighttime land surface temperatures from satellite data confirmed the large differences between areas of impervious surfaces and tree cover, suggesting a urban heat island effect at nighttime. In general, however, the nighttime urban heat island effect was weaker than during daytime and this effect was reversed along some altitudinal gradients due to localized atmospheric convective forces. Further exploration of the relationship between the urban heat island and actual energy bills needs to be undertaken.

A time series of urban forestry in Los Angeles

In an effort to understand the evolution of changes in tree canopy cover and tree density over time in Los Angeles several geographic information systems (GIS) and remote sensing methods were deployed. First historic and digital aerial photography within Los Angeles California since the 1920's were used. We next relied on spaceborne satellites for the more contemporary period to evaluate change in tree canopy cover.

By combining historic and digital aerial photography we were able to develop high temporal resolution (4–6 time periods) of three regions from within Los Angeles (San Fernando Valley, Hollywood, and the Los Angeles Basin). This revealed that there has not always been a direct linear increase in tree density relative to time (Fig. 3). Clearly in this Mediterranean region, trees reflect human intervention as the archeological record shows sparsely treed grasslands, swamps, trees along the riparian corridors and oak and black walnut savanna along the foothills where groundwater is in reach.

We also found that public and private lands that were rural in the 1920's experienced a linear increase in tree densities as they urbanized, whereas tree density on urbanized lands (such as Hollywood) peaked in the 1940's and quickly declined. However, on the whole, historic tree densities sampled from all 15 city council districts in Los Angeles from the 1920's, 1950's indicate that most districts experienced a significant increase in tree cover (Fig. 4).

GIS data illustrate the densities of tree cover from the 1920's, 1930's, 1940's and 2006. Data also shows that trees on public and private land are generally the first planted in suburbanizing areas. Over time, tree densities on private land increase to a higher density than trees on public land. For instance, Los Angeles currently averages approximately 104 mature trees per hectare (82 on private land and 22 on public land) and most of this urban tree canopy in Los Angeles is on private land. This is not to say, however, that there isn't significant room to expand the canopy utilizing public properties.

We also utilized a number of indices from high spatial resolution spaceborne satellites like QuickBird, Landsat, and MODIS to develop further information on tree canopy changes in Los Angeles in the contemporary period. QuickBird was used to provide high resolution data (1 m) on tree canopy cover for the city of Los Angeles (Fig. 5). One of the most widely used indices in remote sensing to estimate vegetation productivity is the Normalized Difference Vegetation Index (NDVI), the ratio between the red and infrared bands (Goward et al. 1985). NDVI has been associated with net primary productivity, actual evapotranspiration, and biomass (Chong et al. 1993). Los Angeles has become generally greener over the last 33 years based on Landsat (see Fig. 3) and markedly so since the 1975's. However areas around roads have lost trees in the city of Los Angeles (see Fig. 4). MODIS continuous canopy cover has been used to show tree canopy density in 1 km pixel resolution (Fig. 5). It can also provide near real time assessment of city council districts and neighborhoods.

In sum, the results demonstrate that it is possible to reconstruct the development of urban forests in cities with a high degree of spatial resolution over time. This aspect of our research demonstrates the importance of human impacts on ecosystems and of human preferences on urban tree canopy cover.

Implementing the planting of a million new trees

Planting trees in cities, as we discussed above, is believed to create multiple ecosystem services and benefits for humans. But despite the alleged potential for such services and benefits, in this difficult fiscal period in California there is little public money for cities to create new programs and to implement new approaches. Understanding how a city might achieve ambitious tree planting goals under such constraints has been another aspect of our project.

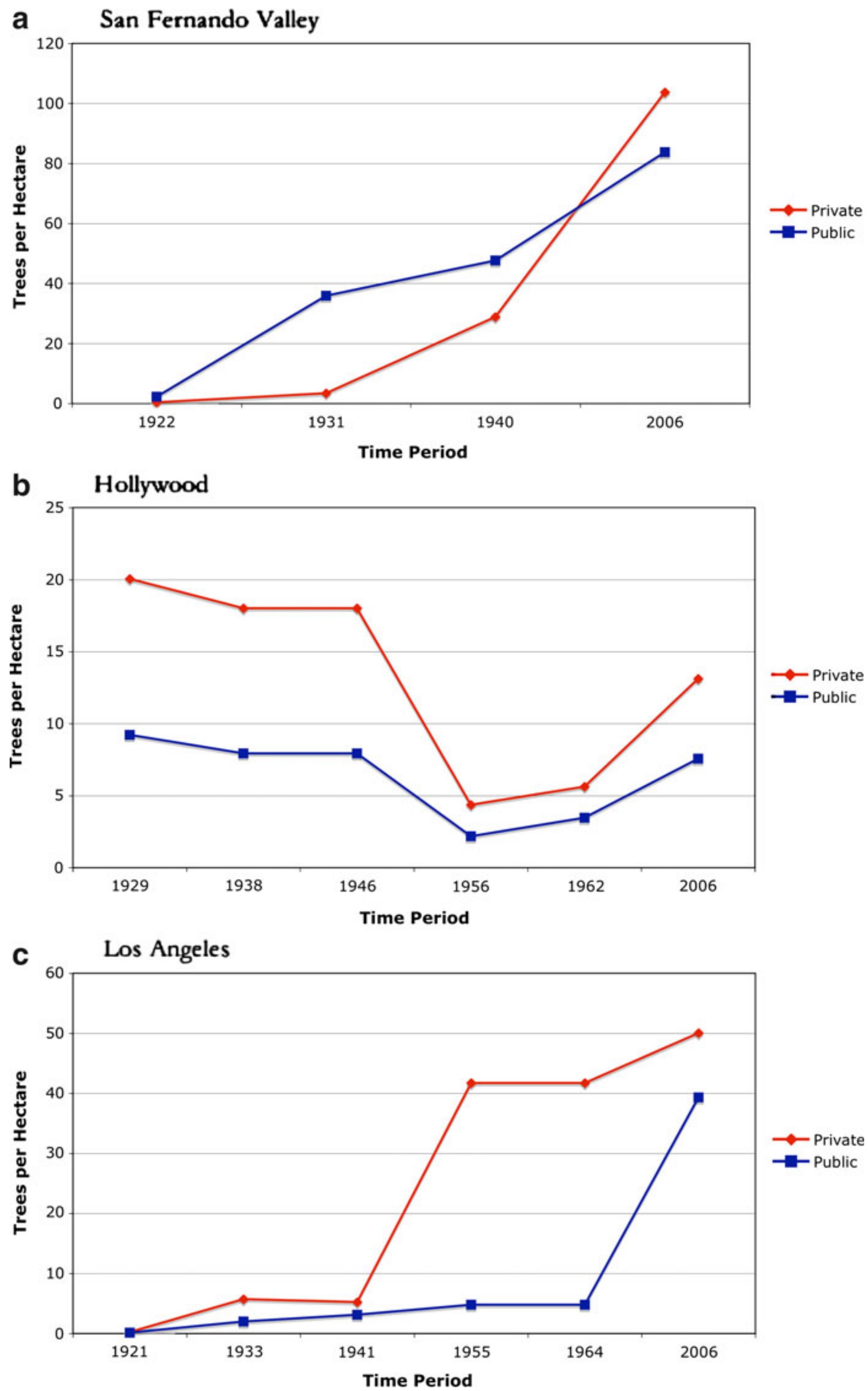

Fig. 3 Changes in tree canopy cover over time in three different neighborhoods (Gillespie et al. 2011)

Street trees in Los Angeles are under the administration of the Urban Forestry Division in the Bureau of Street Services, which is part of the City's Department of Public Works. Its staff consists of 8 arborists and three regional managers, as well as a director and a clerk for the city's 498 square miles. Tree pruning

Fig. 4 Examples of GIS data illustrating densities of tree cover from the 1920s, 1930s, 1940s and 2006

rotations, for example, are now approximately 100 years. The Department of Recreation and Parks is the other department responsible for trees, and it maintains trees in the city's parks. Both of these departments have been suffering substantial budget cuts since the 2000s and they were not capable of undertaking this new infrastructure program.

Rather than relying on the existing Urban Forestry Division of the Department of Public Works and providing it with more resources, Million Trees Los Angeles (MTLA) was created as a special program to be implemented outside of regular city departments by city nonprofit groups, but with the collaboration of existing city departments. A plan was developed by a task force of local nonprofit tree planting organization members, academic experts, nursery industry representatives, and the staff of relevant city departments. MTLA was launched by partner nonprofit organizations with high profile tree plantings and tree sapling give-aways, with the understanding that the Mayor would raise private funds for the MTLA (Pincetl 2010a). As the implementation began, issues started to arise, including the lack of secure funding, competition between nonprofit organizations contracted to plant trees, poor nursery stock, and the lack of criteria for distributing trees. These issues compounded the sense of urgency to plant as many trees as possible to fulfill the Mayor's promise, led to management

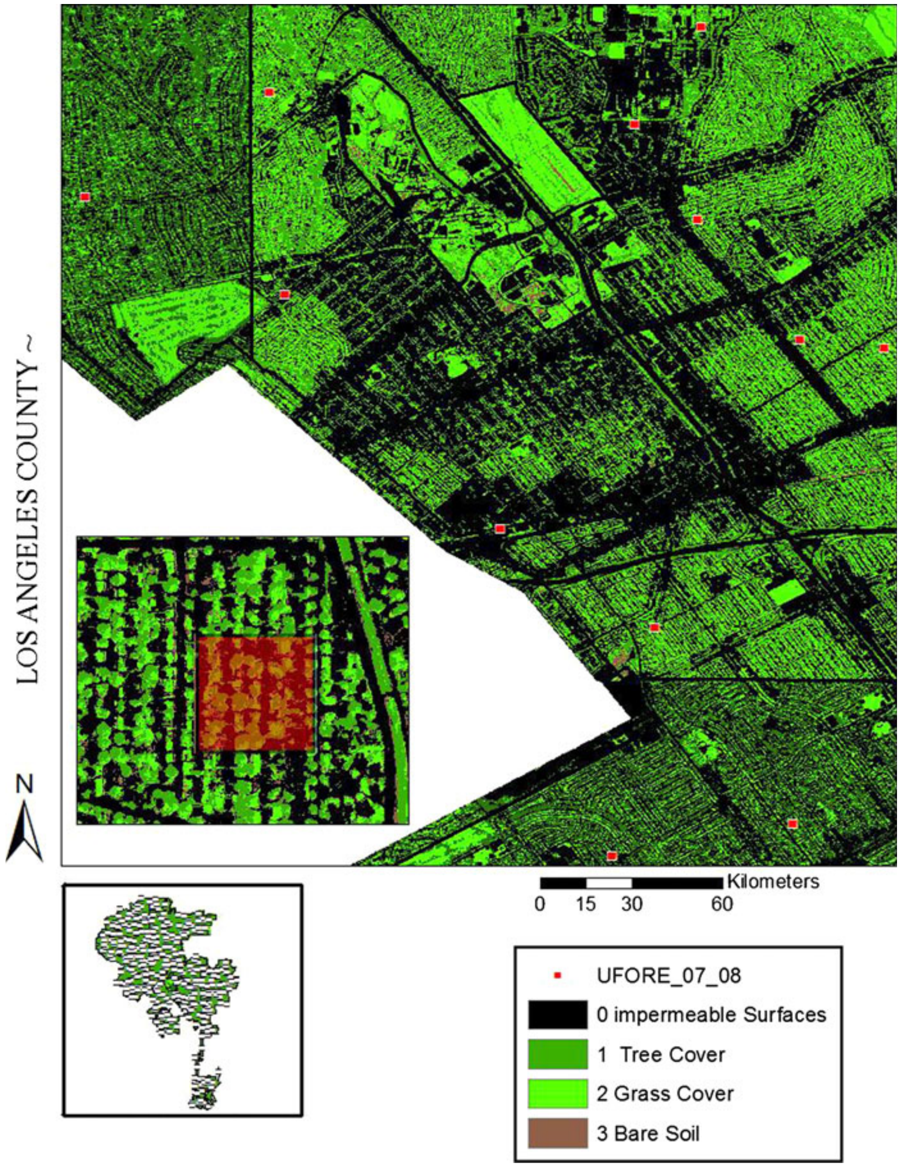

Fig. 5 Resolution of Urban Forest Effects (UFORE) plots (n = 240) and Tree Canopy Cover (2 m) data (McPherson et al. 2007) available for the City of Los Angeles over three spatial scales

problems, and invited outside scrutiny (Zahniser 2007).

The political importance of MTLA's success for the Mayor led to moving the program into the Mayor's office to better control it. This situation highlights the ambiguity of MTLA relative to its purpose and construction: political campaign promise—following the fashion trend set by New York City's Million Trees—or function: a new approach to infrastructure to make the city more sustainable, or both. Trees were touted as cooling the urban heat island, mitigating stormwater, improving public health, but MTLA was managed as a stand-alone program rather than integrated with any existing city departments.

By contrast the New York City Million Tree Planting Program (also a public/private partnership) is assuming responsibility for planting 60% of all of the new trees, itself. The New York Parks Department will spend about $400 million to plant 600,000 trees (Cardwell 2007) and it is hoping that private landowners will plant the remaining 400,000 trees on their properties. The program was launched by the Parks Department and New York Restoration Project in collaboration with many partners. To raise the millions of dollars needed to fund this program, New York City received help from a number of philanthropic organizations. For example, the Bette Midler Foundation committed to help raising $200 million (Danis 2007). In Los Angeles, there was no such commitment.

Questions of transparency also emerge from relying on public private collaborations to deliver services about the governance of urban systems (Wolch 1990; Staehli 1997; Salamon 2002; Pincetl 2003; Morris 2009). While New York City has a public plan for tree planting and transparent accounting for funds, this is not the case in Los Angeles where funding is blended and difficult to trace. Traditionally most governmentally-initiated and paid-for public works programs (and other city programs) are subject to planning and implementations processes, requirements and standards, including budgeting standards. They generally go through public hearings and evaluations. When there is a mixed partnership, these processes can often be more opaque. MTLA has not made its funding streams transparent, there is no publicly available plan for planting, and no public participation for guiding tree planting in the city. This first led to suspicion (especially by the press), and now, near invisibility in the public eye (Zahniser 2007).

Since there was no public funding available to expand the mission of the existing Urban Forestry Department, and since tree planting was not understood by its proponents as an initiative that required planning, expertise and institutional capacity to sustain over time (Swiller 2007), MTLA was launched as a public–private partnership that was to rely on the nonprofit sector to plant the trees and to help raise the funds to do so.

Collaborative grant proposals were written to the State's forestry agency, CalFire, which receives federal Forest Service funding to fund local urban forestry programs, among other funding sources, including private sources such as Home Depot. This shows that in Los Angeles, tree planting lies between beautification and new green infrastructure, and illustrates the funding support for urban tree planting by the FS. While there are scientific claims behind the tree planting relative to environmental benefits, as we have shown, they are unsubstantiated empirically—no real research was conducted in LA to determine the most climate appropriate tree species, best planting locations, impacts on neighborhoods and potential ecosystem services—and the city has done little to craft its tree planting plan so that it would provide optimum ecosystem services.

In Los Angeles, irrigating trees in the public right of way is the responsibility of local residents, and they assume the water costs and the burden of ensuring that trees are sufficiently watered as well as tree maintenance costs. For more affluent neighborhoods that have gardeners, such maintenance is not significant, but in other neighborhoods trees are often seen as a nuisance (Pincetl 2010b). They are perceived to be linked to crime and their ecosystem benefits, like cooling the atmosphere (which is often recognized), are still generally not considered important enough to overcome maintenance issues. Benefits from TCC ecosystem services are public, but costs are left to the good will of private parties, which likely leads to free riding. By contrast, the gray infrastructure costs, such as sewage pipes or water filtration, and its maintenance is borne by the tax paying public as a whole.

Programs such as MTLA that involve imbricated public/private arrangements also entail relations of power and authority. Governance structures matter in how new programs are developed and implemented. Since the city of Los Angeles is a charter city, the Mayor's office has considerable authority over the city bureaucracy while the Mayor's office itself is largely autonomous. The charter city status enables the Mayor to create programs for which the Mayor's office itself can direct and finance via private donations. While providing a great deal of flexibility, such authority can also create tensions with other elected officials such as the city council about control over programs and policies. Knowing the structure of the local government and the flows of money and power are important in program evaluation as these can reveal power relations and special relationships that affect programs. (Pincetl 2010b).

Conclusions

The research involved coupled socio-ecological methods—biophysical measurements in the city, social science analysis to correlate the measurements to benefits claims—to analyze a program developed during a mayoral campaign and aimed to make Los Angeles the greenest large city in the United States. Concerned about the city's livability and environmental impacts, the mayor proposed to plant an additional million trees for their ecosystem services benefits. His initiative was based on popular claims of urban forest benefits.

The main findings from this research are as follows:

- Tree canopy cover in Los Angeles has increased over time, but it shows pulses related to land (re)development and road building.
- Los Angeles has planted between 170,000 and 250,000 trees over 5 years despite budget constraints (Bure, personal communication 2011). However, the exact number of trees planted and their survival rate is unknown.
- This slightly disappointing rate of tree planting can be partly explained by our economic analysis, which shows that many private property owners have no financial incentives to plant trees on their properties. This is the case for both single family and multi-family buildings.
- Where tree cover is high, air temperatures are measurably lower.
- There are no environmental criteria to guide tree selection, such as size of canopy when full grown to reduce the urban heat island, or their impacts on water use. Yet water use by some commonly planted tree species is potentially significant.
- Los Angeles has been successful in enlisting a number of community-based partners in the city to plant trees when it was able to fund those groups.
- The MTLA does not have an identifiable plan for implementing its goals. Instead it plants opportunistically where partnerships can be forged.
- Tree maintenance is borne either by residents or by nonprofit organizations. The city itself has no budget to water or maintain trees.
- Transparency is lacking as there are no mechanisms for public participation.
- MTLA may be fragile as it relies on the will of the mayor.
- There is no monitoring of the effects of tree planting on the city's environment.

The complexity of implementing such a program in an era of budget constraints, and the costs of implementing large tree planting programs point to the need for detailed research on the ecosystem benefits and the implementation challenges in other cities. As urban areas attempt to develop programs to become more sustainable, applying the research methods pioneered in this research should help to better evaluate the costs and benefits of ecosystem services-based environmental programs in specific places. Clearly one important factor that needs to be consistently taken into account is that climate and ecosystems vary significantly across the country, as well as people's preferences for trees, which has an impact on the value of these and the ecosystem services will vary widely. Thus the services need to be chosen carefully. Drier, warmer climates have different constraints than more humid climates, and cold climates have still others that should drive species selection and design of the service.

Further, it cannot be assumed that people's values relative to ecosystem services are the same across the country either, and it may be that aspects of these services may or may not be popular, which affects the success of their implementation. This is especially true where residents must assume a large responsibility for the maintenance of the service, such as trees. Moreover, findings such as the impacts of tree canopy cover on the urban heat island in the Southwest come with complex trade-offs: tree maintenance and/or watering requirements versus cooling; cooling versus water transport and energy needed to do so (Guhathakurta and Gober 2010).

It is also important to put the interest in ecosystem services such as urban tree planting in a historical and political perspective. Urban tree planting is a historical phenomenon and comes about due to a confluence of factors. Over the past 30 or more years, the US Forest Service has worked successfully to increase interest and commitment to tree planting for the positive environmental effects of trees. Now many cities across the country have embraced tree planting for their alleged benefits, yet our research shows such programs may also entail disamenities and costs. Therefore, if such programs are to succeed, there is need for better science that takes local ecological and human/social conditions into account to maximize the net benefits of tree planting. It is necessary to clarify to what extent these approaches can provide tangible benefits, or if they are rather the product of cultural preferences that emerged from a particular time in history. The specific conditions in the Los Angeles case may be unique, but the research suggests that tree planting for ecosystem and human services needs to be implemented differently in different places, and perhaps even, for different goals—well-being, shading, or simply beauty. Whatever the reason, it should be arrived at through public, transparent and democratic processes.

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