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A method for locating potential tree-planting sites in urban areas: A case study of Los Angeles, USA

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Abstract

A GIS-based method for locating potential tree-planting sites based on land cover data is introduced. Criteria were developed to identify locations that are spatially available for potential tree planting based on land cover, sufficient distance from impervious surfaces, a minimum amount of pervious surface, and no crown overlap with other trees. In an ArcGIS environment, a computer program was developed to iteratively search, test, and locate potential tree-planting sites by virtually planting large, medium and small trees on plantable areas, with large trees given priority as more benefits are expected to accrue to them. A study in Los Angeles, USA found 2.2 million potential planting sites, approximately 109.3 km^2 of potential tree canopy cover.

Keywords: GIS; Land cover; Potential tree planting; Quickbird image; Tree canopy cover; Urban forest

Introduction

Urban land in the United States is projected to increase from 3.1% in 2000 to 8.1% in 2050, an area of 392,400 km^2 (Nowak and Walton, 2005). Urbanization creates significant changes in land use and land cover, affecting the structure, pattern and function of ecosystems. The public is increasingly concerned about how these changes influence daily life and affect the sustainability of 'quality of life' for future generations. Trees in urban settings play an important role in improving urban life by reducing runoff, air pollution and energy use, and improving human health and emotional well being. Tree canopy cover is the urban forest's driving force for producing benefits for the community (Rowntree and Nowak, 1991; McPherson, 1992; McPherson et al., 1997; Nowak et al., 2002). Expanding the urban forest through tree planting is considered one of the most cost-effective means of mitigating the urban heat island effect and associated expenditures for air conditioning (Simpson and McPherson, 1998) and is one solution to common urban social, environmental, and economic problems. More studies on benefits of trees in urban setting can be found in the literature (Schroeder and Cannon, 1983; Ulrich, 1985; Heisler, 1986; Dwyer et al., 1992; Hull, 1992; Sullivan and Kuo, 1996; Scott et al., 1998; Wolf, 1999; Nowak et al., 2000; Nowak and Crane, 2002; Xiao and McPherson, 2002).

Estimating potential tree canopy cover and identifying potential tree-planting sites is important for expanding the urban forest. Potential and existing canopy cover has been analyzed for several cities (Rowntree, 1984; Nowak et al., 1996). Traditionally, potential canopy cover is defined as the percentage of total land area that

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is pervious and without tree canopy cover. In this study of the city of Los Angeles, CA, USA, potential tree-planting sites are located virtually using GIS-based decision rules that eliminate sites that are too small or too close to other urban infrastructure. The virtually planted potential trees can be counted and their canopy summed to project potential canopy cover. This approach provides more realistic estimates of tree-planting potential than are obtained using the traditional approach. Therefore, we define potential tree canopy cover as the sum of canopy cover area from all virtually planted trees at maturity. Existing canopy cover refers to the total crown projection area of trees currently within the city.

Related work: tree-planting strategies

Tree placement is a key element in urban landscape architectural design. Many factors need to be considered when selecting sites for tree planting in urban areas. Important site conditions related to tree selection include climate factors, soil characteristics, environmental conditions, planting space, site location, existing vegetation, aesthetics, land ownership and regulations, social influences, and maintenance requirements (Bassuk and Trowbridge, 2004; USDA Forest Service, 2005). Some communities have ordinances restricting placement of trees within a specified distance of a street, sidewalk, streetlight, or other utilities (Bassuk and Trowbridge, 2004; USDA Forest Service, 2005).

Tree-planting strategies can be grouped into three major categories: (1) ensure survival rate and good physical growth (Coder, 1996; Gilman, 1997; Van Elegem et al., 2002; Carver et al., 2004), (2) enhance aesthetics (Arnold, 1980), and (3) maximize environmental benefits, such as energy conservation and reduction of the urban heat island effect (McPherson et al., 1994). Coder (1996) provided instructions and formulas for using specific criteria to determine the suitability of a site for a specific tree based on the open soil surface area and volume of soil available to be colonized by roots. Factors considered by Coder (1996) in his five-step process for determining the necessary area for planting a tree include current tree diameter, annual growth, tree life span, and management objectives. Gilman (1997) suggested various minimum widths of planting sites for trees with different mature sizes: 3–4 ft for small trees, 4–6 ft for medium trees, and greater than 6 ft for large trees, with 1 ft equaling about 30 cm. Van Elegem et al. (2002) used a step-by-step multicriteria methodology to select the most suitable and feasible locations for the establishment of large urban forests, with a view to achieving the highest chance of successful implementation. Carver et al. (2004) developed a decision support model to generate riparian tree-planting recommendations based on site characteristics. Arnold (1980) advocates the collective use of trees in groves, rows, and symmetrical units in urban design, and explains aesthetic principles used in grouping trees in a variety of settings. He also discusses how to select the appropriate species of tree for each situation, and how to best utilize trees in a specific site. A study in Chicago, IL, USA, by McPherson et al. (1994) indicated that the best place to plant a tree around a home to reduce peak cooling costs was opposite west-facing windows and walls, while the next best place to plant a tree was opposite the east wall. Creating windbreaks to the north and northwest of a structure in Chicago where winters are long and windy is considered the most valuable way to use trees to reduce energy use in winter (McPherson et al., 1994). The studies by Van Elegem et al. (2002) and Carver et al. (2004) relate to the larger scale, while Arnold (1980) and the Chicago study (McPherson et al., 1994) refer to the tree planting at the smaller scale: detailed individual tree placement related to surrounding objects. This study, focusing on site spatial availability, used a combined approach that identifies potential tree-planting sites for individual trees across a large study area.

Methods

Study site

Our study site was the city of Los Angeles, California, one of the largest metropolitan areas in the United States. It has a total land area of 1225 km^2 and is undergoing a period of rapid population growth. Improving air quality, alleviating water shortages, reducing the urban heat island effect, and reducing stormwater runoff are challenges facing Los Angeles. With a current population of nearly four million, rapid growth in Los Angeles is accelerating these problems. Plagued with traffic problems and poor air quality, Los Angeles is more often equated with urban sprawl and asthma than sustainability (Krimmel, 2007). These problems need solutions as the region tries to protect and restore environmental quality while enhancing economic opportunity. As tree canopy is a valuable component of Los Angeles's urban ecosystem, increasing tree canopy cover could be part of the solution to Los Angeles's social, environmental, and economic problems. Los Angeles Mayor Antonio Villaraigosa has made it one of his goals to transform his city into "the greenest big city in America" (Krimmel, 2007).

Los Angeles is characterized by diversity in land use, buildings, and types of vegetation. Over 15% of the urban area, 203.6 km^2, consists of naturally vegetated mountains. Topographic gradients are small for most land areas, but large in the mountainous areas: the elevation changes from sea level to 1543 m at Mount Lukens in the northeast corner of the city. Because vegetation management on the naturally vegetated mountains is different from the rest of urban area, mountains were excluded from this study; the remaining study area is approximately 1021.4 km^2 (Fig. 1).

Los Angeles includes five major land use types: low-density residential, medium- to high-density residential, industrial, commercial, and institutional. Low-density residential land predominates in the city, occupying approximately 48% of the total area, while medium- to high-density residential, industrial, commercial, and institutional areas cover 17%, 10%, 8% and 16%, respectively. A small portion of the city has not been characterized and was labeled as unknown. The city is divided politically into 15 council districts or 86 neighborhood councils.

Data set

Land cover data derived from remote sensing data were used in this study as a base map for locating potential tree-planting sites. The imagery used for the land cover classification consists of 64 scenes collected by QuickBird satellite in different seasons from 2002 to 2005. It includes four multispectral bands (blue, green, red, and near-infrared) with 2.4 m (7.9 ft) spatial resolution and a panchromatic band with 60 cm (2 ft)

Fig. 1. Study area.

Table 1. Land cover classification error matrix

	Reference (pixel)				User's accuracy (%)	Classification (pixel)
	Tree	Irrigated grass	Bare soil/dry grass	Impervious		
Classification (pixel)						
Tree	**145,335**	17,290	1402	41,290	205,317	70.8
Irrigated grass	25,451	**65,188**	1435	17,737	109,811	59.4
Bare soil/dry grass	2871	5989	**2717**	21,258	32,835	8.3
Impervious	21,905	11,369	4795	**1,134,016**	1,172,085	96.8
Column total (pixel)	195,562	99,836	10,349	1,214,301	1,520,048	
Producer's accuracy	74.3%	65.3%	26.3%	93.4%	Overall accuracy: 88.6%	

Bold values are the number of pixels that have been correctly classified.

spatial resolution. Before it was used for land cover classification, the multispectral imagery was pan-sharpened using the high-resolution panchromatic imagery. A moving masks method (Xiao et al., 2004) was used in conjunction with supervised and unsupervised classifications to map the land cover of the study area. This mapping method had been widely used in urban land cover mapping (Stow et al., 2003). The data analysis was performed in ENVI (Environment for Visualizing Images, Research Systems Inc., Lafayette, CO, 1997) and ArcGIS (Environmental Systems Research Institute Inc. 2006). Four types of land cover were distinguished: impervious surfaces, tree canopy, irrigated grass, and bare soil/dry grass. Fifty parcels randomly selected throughout the city were digitized from the pan-sharpened multispectral images to assess the land cover classification accuracy. Classification result was compared to digitized result for the 50 parcels and summarized as an error matrix (Table 1). The overall land cover classification accuracy was 88.6%. Observations also found that many misclassified pixels occurred along the edge between two classes, similar to what was reported by Myeong et al. (2003). Other types of misclassification were found between tree canopy and irrigated grass and between bare soil/dry grass and impervious surfaces due to their spectral similarity. Particularly, on the images collected during June–September, deciduous trees with high spectral reflectance were misclassified as irrigated grass, which, when added to the misclassification of impervious area around tree canopy as bare soil/dry grass, overestimated the overall pervious area within the city. Land cover classification errors have an impact on the accuracy of the identified potential tree planting. But, other than eliminating discrete single pixels, no preprocessing was done to refine the land cover map for the potential tree-planting site identification. A parcel polygon shape file was also obtained from the City of Los Angeles and was used to locate ground-truthing locations for conducting the accuracy assessment of the planting sites.

Identifying planting sites

Lack of information on buildings, sidewalks, utilities, etc. prevented us from taking all tree-planting factors into detailed account during our identification of potential tree-planting sites in the city. Our tree-planting strategy focused on the spatial availability of a planting site. Three sizes of trees were used in our potential tree-planting site identification: large, with an approximate mature crown diameter of 15.2 m (50 ft); medium, 9.1 m (30 ft); and small, 4.6 m (15 ft).

Criteria for selecting potential planting sites were set as follows: (1) grass, dry grass, and bare soil land covers are considered plantable; (2) tree trunks must be at least 0.6 m (2 ft) from any impervious surface, including buildings; (3) the minimum pervious surface required for small, medium and large trees was set as 1.5 m^2 (16 ft^2), 3.3 m^2 (36 ft^2), and 9.3 m^2 (100 ft^2) respectively; (4) no crown overlap is allowed between existing trees and potential trees, or between potential trees; and (5) as more benefits accrue from larger trees (McPherson, 2003), large trees are given priority.

Placing trees on planting sites

Analysis on the pervious areas for different land use areas found that the pervious areas on residential, industrial, and commercial land use area are relatively small (size may range from 0 up to 465 m^2 [5000 ft^2], with an average size less than 186 m^2 [2000 ft^2]), which are only available for a few large or medium size trees. While pervious areas on institutional land tend to be homogenous and have a much larger size (size may range from 465 m^2 up to 930 m^2 [5000 ft^2 up to 100,000 ft^2] or even larger). Those relatively small pervious surfaces are more likely to be suitable for tree planting compared to the very large pervious areas in institutional land use, which often have been left open intentionally for use, for example, as athletic fields. Our potential tree-planting strategy was to plant a tree in the

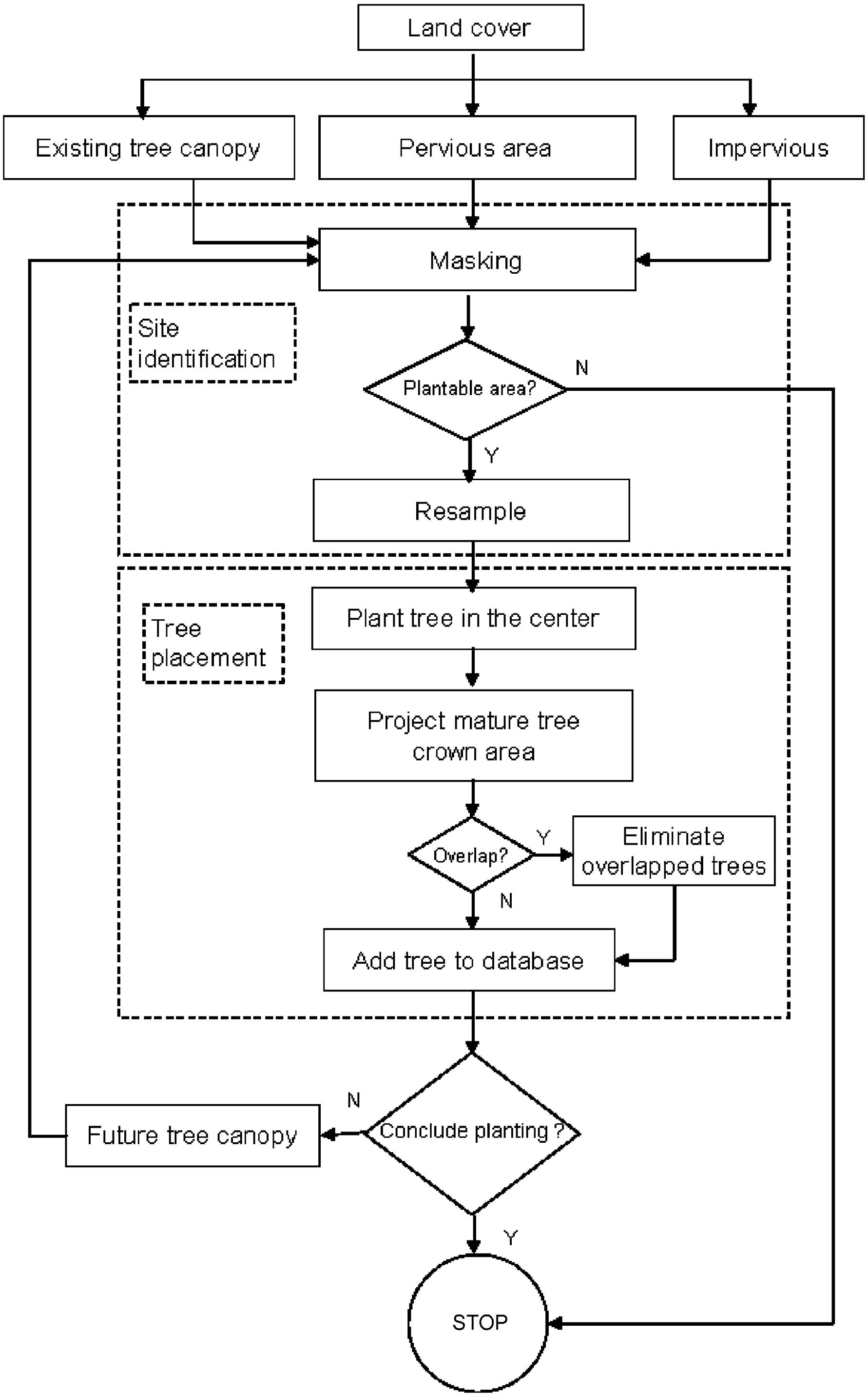
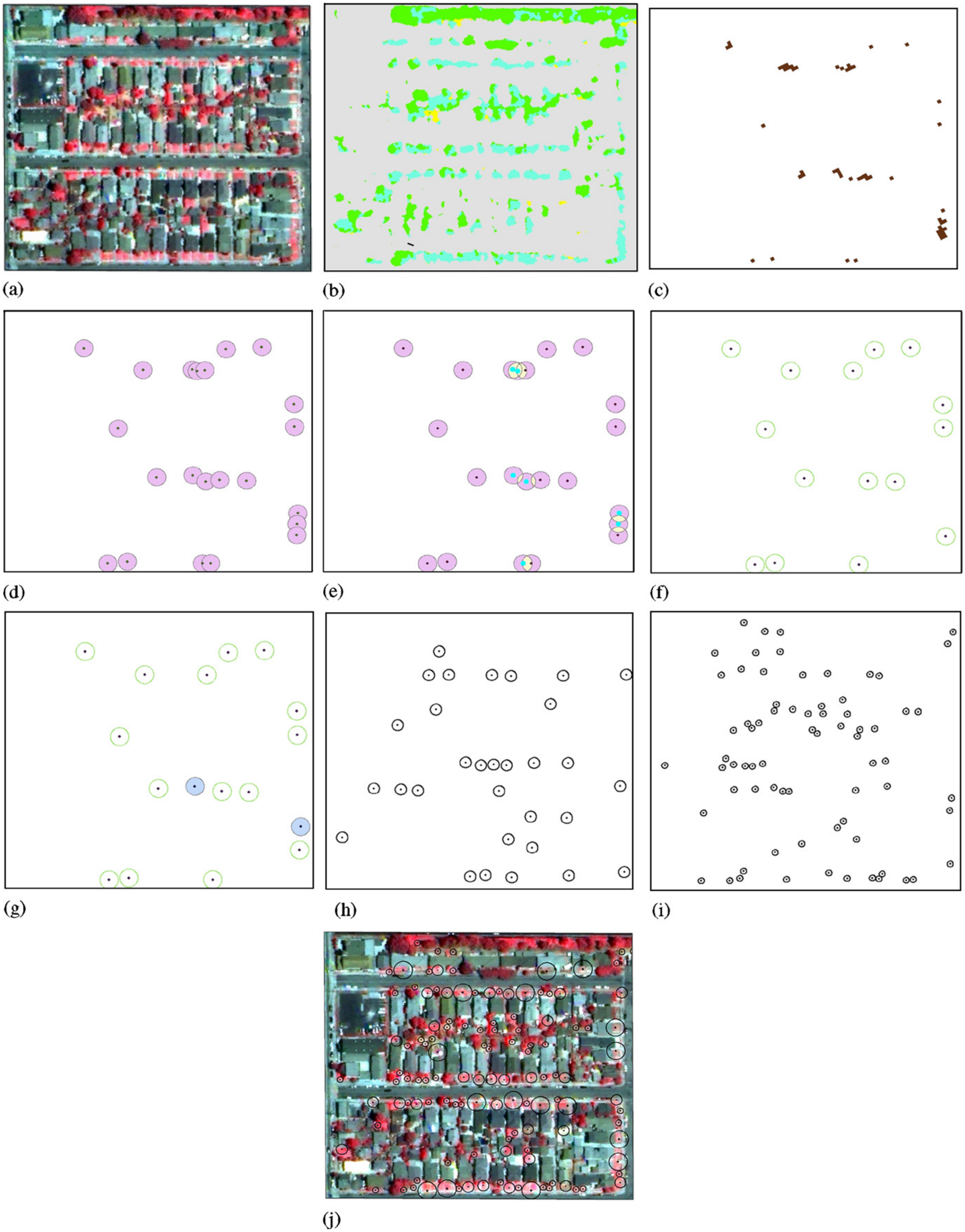


Fig. 2. Flowchart of tree planting.

center of each plantable site, and then iterate the procedure until all plantable spaces were filled up or until the number of new trees added with each iteration was negligible.

A computer program was developed under the ArcGIS environment to iteratively search, test, and locate potential tree-planting sites. This program includes two major modules: site identification and tree placement (Fig. 2). The site identification module identifies planting sites, and the tree placement module virtually plants trees on each identified planting site. Planting site identification began by locating pervious areas and applying the potential tree-planting criteria to identify plantable sites. During this procedure, areas that were too close to buildings, paving, and existing trees were masked out to avoid conflicts between tree


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)

trunks and roots and to avoid overlaps with existing trees. The program then resampled the potential planting area to ensure that each tree would be allotted sufficient space to grow. The tree placement module started by planting a tree in the center of each plantable site, and then projected the mature tree crown projection area to check for potential overlaps. After eliminating either of the two overlapping trees, the module saved potential trees to a tree database.

Before the program began another cycle, future tree canopy cover for the potential trees inside the database was mapped to ensure that the potential trees to be planted in the following run would not overlap with any previously planted ones. Except when signaled to conclude planting, the program would repeat itself until no additional planting sites could be found. Because large trees produce proportionately greater benefits than small trees (McPherson, 2003), the program starts by filling sites with large trees, then medium, and small trees. Fig. 3 demonstrates the tree-planting procedures and the final result at a residential sample site.

The number of iterations can be decided by the user, depending on the extent to which the potential planting sites need to be filled. Our test found that filling large pervious surface with trees is costly, for example, to fill a football field size pervious area [$109.7 \times 48.8\,\text{m}^2$ ($360 \times 160\,\text{ft}^2$)] with trees would require approximately 12 iterations. Tests also found that, for each size of potential trees, the number of trees that could be planted dropped substantially from one planting cycle to the next, especially from the first cycle to the second (Table 2). Due to the computational cost, our tree planting in Los Angeles was limited to a maximum four iterations for each size of trees. By stopping at four iterations we accepted a compromise between allowing a few trees to be planted in undesired areas, such as athletic fields, while leaving other large plantable areas, such as vacant lots, incompletely filled. This approach simplified the tree-planting procedure and reduced computational cost but sacrificed a number of potential trees in large pervious areas, particularly the pervious areas on institutional land (Fig. 4).

Accuracy assessment

Errors associated with remote sensing and GIS data acquisition, processing, analysis, and final product presentation can have a significant impact on the reliability of the data (Lunetta et al., 1991), making accuracy assessment an important step in the process. However, accurately assessing the errors associated with remote sensing and GIS data remains a research challenge. A review (Janssen and Vanderwel, 1994) on accuracy assessment of satellite-derived land cover data found that only a limited number of methods are available for assessing data accuracy, and the applied definitions differ very much from author to author. The quality of GIS data is difficult to evaluate because many criteria are involved. For example, Guptill and Morrison (1995) determined the accuracy based on completeness, consistency, lineage, and positional, attribute, semantic, and temporal accuracy.

Table 2. Number of trees planted in each planting cycle on a sample site

Planting cycle	Large	Medium	Small
1	1155	3434	10,561
2	189	254	1,520
3	64	48	93
4	34	NA	NA
Total	1442	3736	12,174

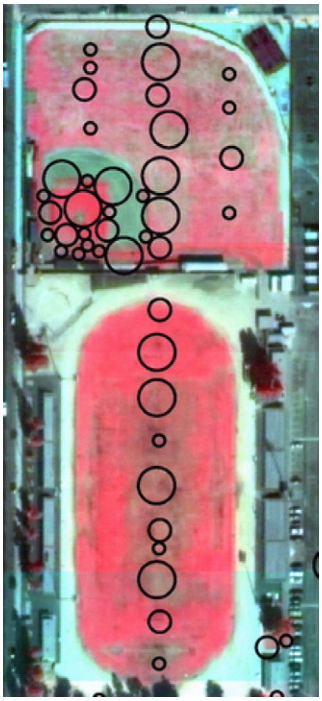


Fig. 4. Tree-planting result on institutional land with limited iterations.

Fig. 3. Tree planting demonstration on a residential site: (a) Color infrared image, (b) Land cover, (c) Identified plantable sites for large trees, (d) Plant a tree in the center of each planting site and project future crown area, (e) Identify overlapping and eliminate overlapped trees, (f) Large trees planted in the first run, (g) Newly planted trees were treated as existing trees and tree planting was repeated resulting in two more large trees, (h) Similar procedure was conducted and medium trees were planted, (i) Similar procedure was conducted and small trees were planted and (j) Potential trees planted.

This study used a series of GIS functions (e.g., buffering, resampling, masking, raster-vector conversion, and intersecting) to virtually plant potential trees on planting sites that were identified as appropriate from the remote sensing-derived land cover data. Two major errors detract from the overall accuracy of potential tree-planting sites identified in this study: errors associated with the initial land cover data and errors associated with the GIS-based tree-planting process. Quantifying errors associated with remote sensing data and determining the propagation of the errors through each GIS operation during the modeling process are difficult. Site visiting was conducted on randomly selected parcels to assess the accuracy (by number of trees and canopy area increase) and to calibrate the tree-planting results.

A stratified random sample of 100 parcels was located across Los Angeles using the UFORE random plot selection tool (Nowak et al., 2003). The number of sample plots was proportional to land use by area: 44% low density housing, 18% medium- to high-density housing, 16% industrial, 13% commercial, and 9% institutional. Two maps for each site were created for ground-truthing: a gray-scale aerial photograph (collected in 2000, 0.15 m [0.5 ft] resolution) with complete street address shown on top (Fig. 5a) and a Quickbird pan-sharpened color infrared image (0.6 m [2 ft] resolution) with circles showing individual potential trees (Fig. 5b). A parcel boundary was also shown on both the images to identify the ground-truthing area. Ground-truthing staff were asked, based on the criteria with which the computer program was developed, to cross out the trees that were misplanted (e.g., in conflict with existing trees or without sufficient open space) and to add those missed by the computer program.

Results

Ground-truthing

After locating the property and obtaining access permissions, personnel from the Los Angeles-based nonprofit organization TreePeople visited 55 of the parcels during September and October in 2006 to conduct the ground-truthing analysis. Potential trees were crossed out or moved around within the ground-truthing area, and new potential trees were added based on spatial availability (e.g., a small tree was added in Fig. 5c). Within the 55 ground-truthing parcels, the computer program generated 877 potential tree-planting sites that increased canopy cover by 3.48 ha (8.6 acres), while ground-truthing results indicated potential for 599 trees that increased tree canopy cover by 3.52 ha (8.7 acres) (Table 3). Overall, the number of ground-truthed

Fig. 5. Ground-truthing maps.

Table 3. Ground-truthing results by land use

Land use	Number of samples	Large trees		Medium trees		Small trees		Total trees		Total potential canopy cover		
		Pred.	GT	Pred.	GT	Pred.	GT	Pred.	GT	Pred.	GT	Accuracy (%)[a]
Low density resid.	24	11	11	21	35	115	84	147	130	0.53	0.57	−7.2
Med.–high density resid.	10	1	1	10	10	17	15	28	26	0.11	0.11	3.0
Industrial	9	28	29	66	33	257	71	351	133	1.37	0.86	58.4
Commercial	7	13	21	38	45	84	67	135	133	0.62	0.79	−20.8
Institutional	5	20	44	35	35	161	98	216	177	0.86	1.19	−28.0
Sub-total	55	73	106	170	158	634	335	877	599	3.49	3.52	−0.9
Total potential canopy cover (ha)		1.33	1.93	1.12	1.04	1.04	0.55	3.49	3.52			
Accuracy (%)[a]		−31.1		7.6		89.3		−0.9				

Pred. – computer prediction, GT – ground-truthed.

[a] The accuracy row/column was calculated as [(Pred.−GT)/GT]∗100%; a negative percentage means an underestimation, while positive one means an overestimation.

Table 4. Ratio estimators used to correct the number of computer-generated potential tree planting sites based on ground-truthing

Land use	Large trees		Medium trees		Small trees	
	Ratio	SE	Ratio	SE	Ratio	SE
Low-density resid.	1	1.54	1.67	1.65	0.73	0.72
Med.–high density resid.	1	0	1	0.63	0.88	0.46
Industrial	1.04	0.23	0.5	0.8	0.28	0.48
Commercial	1.62	1.43	1.18	0.67	0.8	0.49
Institutional	2.2	0.15	1	0.24	0.61	0.07

SE Standard error.

potential tree-planting sites was 32% less than computer-generated sites, but the total potential canopy increase was similar (less than 1% difference). This result is explained by the fact that the ground-truthed sites contained relatively more sites for large and medium trees than were generated by the computer. The predicted potential tree-planting sites for residential land use closely matched the ground-truthed results, but large disagreement existed for the industrial, commercial, and institutional land uses. In addition to the expected underestimation for institutional land use, which was due to the limited number of iterations of the computer program, the disagreement in the number of potential tree-planting sites on industrial and commercial land was found to be associated with incorrectly classified land cover, i.e. impervious surface mistaken for bare soil. Changes in land cover between the time the image was taken and the time of the ground-truthing were also observed, for example, a fruit tree had been removed from the back yard of a house, which resulted in an additional potential tree-planting site.

Potential tree-planting sites

The potential tree-planting program planted a total of 2.4 million potential trees throughout Los Angeles based on the remote sensing-derived land cover data. Ratio estimators (the ratio of the number of ground-truthed tree sites to computer-generated sites) for each tree size and each land use were calculated (Table 4) based on ground-truthing results and applied to adjust the potential tree sites found by computer program. After adjustment, the total number of potential planting sites was reduced to 2.2 million, approximately 109.3 km^2 of potential tree canopy cover. Of the total 2.2 million potential trees, small trees made up the largest portion (58.5%) of the total number, while medium trees accounted for 30.7% and large trees 10.8%. Note that the sample size from most of these land uses is under 10 and has relatively high standard errors, which may impact the overall accuracy of the estimated number of planting sites.

As land use affects the amount of space available for vegetation and is the dominant factor influencing tree canopy cover, a citywide analysis was conducted to tabulate the potential trees by land use. The number of planting sites was rounded to the thousands due to the high uncertainty of the estimation. Table 5 shows the potential tree-planting sites and potential canopy cover by land use after adjustment. Our study found that, similar to Sanders (1984), residential lands have the greatest potential area to plant trees and increase canopy, while commercial/industrial land uses have the least.

Table 5. Identified potential tree planting sites by land use types for Los Angeles

Land use	Total area (km^2)	Existing canopy cover		Potential trees			Potential canopy cover increase		
		km^2	%	Large	Medium	Small	Total	km^2	%
Unknown	14.2	1.3	9.4	2000	5000	15,000	23,000	0.9	6.6
Low-density resid.	486.1	148.1	30.5	89,000	489,000	847,000	1,425,000	62.3	12.8
Med.–high density resid.	177.2	25.7	14.5	29,000	84,000	247,000	360,000	14.9	8.4
Industrial	104.0	3.6	3.5	10,000	7000	11,000	27,000	2.5	2.4
Commercial	81.4	4.5	5.6	11,000	15,000	33,000	59,000	3.5	4.3
Institutional	158.2	29.0	18.4	97,000	79,000	139,000	316,000	25.2	15.9
Total	1021.1	212.4	20.8	238,000	679,000	1,292,000	2,210,000	109.2	10.7

Discussion and conclusion

A GIS-based method for locating potential tree-planting sites for trees of three sizes was introduced and applied in Los Angeles by virtually planting trees in the plantable spaces that were identified based on a remote sensing-derived land cover map. The ground-truthing accuracy assessment found that the program predicted potential canopy cover very well (less than 1% difference between predicted and ground-truthed cover), although the number of potential trees was different. Ground-truthing results were then used to calibrate the outcome of the computer program and the total potential tree-planting sites were reduced from 2.4 million to 2.2 million. The 2.2 million potential sites were expected to add 109.3 km^2 (27,021 acres) to the current canopy cover if all sites were planted and all trees reached their expected mature size. By identifying the number of potential tree-planting sites throughout the city, this study verified that planting an additional 1 million trees within the city is feasible. By determining the distribution of potential planting sites by council district and land use, this study also provided a basis for initial goal setting for the Million Tree initiative.

Note that this method only focused on potential tree-planting sites in pervious areas. Some impervious areas, such as parking lots, offer additional planting possibilities. If these sites were included, the number of overall potential tree-planting sites would be greater than 2.2 million. Also, with a limited number of iterations (here three or four), this method was found to work best for residential, commercial, and industrial areas where individual areas of pervious surface are small. The method can be improved in the future by extracting institutional land from the data set to apply a land-use specific potential tree-planting strategies.

The potential tree-planting criteria were set to allow no crown overlap between existing trees and potential trees, or between potential trees to ensure that each tree has sufficient space to grow and to simplify the tree-planting procedure. If optimum stocking and site-specific benefits (Richards, 1992) are considered, this method will require more spatial details, and the program can be modified to allow a certain level of tree crown overlaps. Following the first stage of a large scale tree-planting project (e.g., LA one million tree initiatives), the virtually planted potential trees are expected to be accepted, deleted, or locally relocated to optimize the aesthetic or environmental benefits.

The accuracy of potential tree-planting sites was found to be highly dependent on the accuracy of land cover classification. Hence, this method will be more promising with more accurate land cover data. Tree canopy cover mapping accuracy was strongly affected by spatial resolution. Unlike trees in rural forests that tend to form continuous canopies, trees in urban settings are often single trees or isolated groups. The influence of background, such as soil and shadow, makes the problem of characterizing trees by remote sensing even more difficult. In such cases, the high spatial resolution of remotely sensed data is important for urban vegetation mapping (Xiao et al., 2004). Land cover mapping methods are usually site-specific and image-specific. A variety of approaches can be used to improve the classification accuracy under different image conditions: texture analysis (Haralick et al., 1973; Myeong et al., 2003; Tsai and Chou, 2006), support vector machines (Pal and Mather, 2005), region-based (Carleer and Wolff, 2006), wavelet approach (Myint, 2006), or classification using additional existing GIS feature layers. A certain post-processing procedure may also improve classification accuracy (Myeong et al., 2003), but should be used with care because it may cause shifts of object edge and change correctly classified pixels.

This study found that smaller trees are more susceptible to land cover classification errors. This can be improved in the future by setting more strict rules for selecting planting sites (e.g. requiring larger pervious surface area for small trees). Although the ground-truthing results were used to adjust the computer-identified potential tree-planting sites, they could not provide precise information on misplanted trees and missed potential sites outside the ground-truthed areas. Neural network and fuzzy decision rule techniques may be used in the future to study and build criteria from the ground-truthing data to refine the computer-predicted planting sites.

As long as land cover information is available, this method can be easily adapted to different regions for tree-planting planning. This method can also be improved in the future to include more spatial details for tree-planting planning, if GIS data for soil types, locations of powerlines, and below ground utilities are available.

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