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Predicting tree species richness in urban forests

Thomas W. Gillespie[1,4] · John de Goede[1] · Luis Aguilar[1] · G. Darrel Jenerette[2] · Geoffrey A. Fricker[1] · Meghan L. Avolio[3] · Stephanie Pincetl[4] · Timothy Johnston[1] · Lorraine W. Clarke[2] · Diane E. Pataki[3]

Abstract There has been an increasing interest in urban forests and the levels of biodiversity they contain. Currently there are no spatially explicit maps of tree species richness in urban areas. This research tests and identifies GIS and remote sensing metrics (climate, area, productivity, three-dimensional structure) hypothesized to be associated with species richness in native forests and identifies methods that can be applied to predict and map tree species richness in cities. We quantified tree species richness, floristic composition, and structure in 28 1-ha plots in the city of Los Angeles. Climate and remote sensing metrics from high-resolution aerial imagery (10 cm), QuickBird (60 cm), Landsat (30 m), MODIS (250 m), and airborne lidar (2 m) were collected for each plot. There were 1208 individual stems and 108 trees identified to species. Species richness ranged from 2 to 31 species per ha and averaged 17 species per ha. Tree canopy cover from QuickBird explained the highest portion of variance (54%) in tree species richness followed by NDVI from Landsat (42%). Tree species richness can be higher in residential urban forests than native forests in the United States. Spatially explicit species richness maps at 1 ha can be created and tested for cities in order to identify both hotspots and coldspots of tree species richness and changes in species richness over time.

Keywords Landsat · Lidar · QuickBird · MODIS · Remote sensing · Species richness · Urban forests

Introduction

Forests can be defined as land cover types covering 0.05 to 1.0 ha plots with trees taller than 2 m to 5 m and a canopy cover of more than 10% to 30% (Penman et al. 2003). By this definition many urban (relating to a city or town) landscapes can be considered forests, and there has been an increasing interest in urban forests and the levels of biodiversity they contain (Grimm et al. 2008). Trees are of foundational importance to urban biodiversity due to their vertical and horizontal structure and tree species richness or alpha diversity is an important metric of biodiversity (MacArthur and MacArthur 1961; Gaston 2000; Bergen et al. 2009). However, urbanization usually reduces both species richness and evenness for most biotic communities and native species diversity (Clarkson et al. 2007; Grimm et al. 2008). Urban forests have been hypothesized to be homogeneous environments with the same tree species planted over wide areas (Grimm et al. 2008; Kowarik 2011). Currently, most plot data from urban forests are small (≤ 0.1 ha) and there are no spatially explicit maps of tree species richness in urban areas (Nowak and Crane 2002; Clarke et al. 2013).

There are a number of climatic and remote sensing metrics that have been associated with tree species richness in native

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The original version of this article was revised: One of the authors name was incorrectly listed as "Darrell E. Jenerette" and should be corrected as "G. Darrel Jenerette".

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✉ Thomas W. Gillespie
tg@geog.ucla.edu

[1] Department of Geography, University of California Los Angeles, 1255 Bunche Hall, Los Angeles, CA 90095, USA

[2] Department of Botany and Plant Sciences, University of California Riverside, 3203 Batchelor Hall, Riverside, CA 92512, USA

[3] Department of Biology, University of Utah, 257 S 1400 E, Salt Lake City, UT 84112, USA

[4] Institute of the Environment and Sustainability, University of California Los Angeles, La Kretz Crossing Suite 300, Los Angeles, CA 90095, USA

forest ecosystems over different spatial scales. Climate (e.g. precipitation and temperature) and potential evapotranspiration have been found to play important roles in determining species richness in forests over large spatial scales (Currie and Paquin 1987; Field et al. 2009). The climatic metric of mean annual precipitation has been associated with gradients of species richness from dry to wetter native forest types and within native forest types (Clinebell et al. 1995; Field et al. 2009). However, studies have noted that within dryland urban forests, climatic metrics are decoupled with species richness due in part to extensive irrigation that overrides the impact of precipitation (Jenerette et al. 2013).

A number of remote sensing metrics from spaceborne sensors have been developed that may be associated with tree species richness in urban ecosystems. Tree canopy cover may be associated with the density of stems, which in turn has been associated with tree species richness in native forests (Conduit et al. 1996). Google Earth imagery at ≤10 cm resolution is available for many urban landscapes and can be used to calculate tree canopy cover and biomass at a high spatial resolution (Ploton et al. 2012). QuickBird imagery has also been used to quantify tree canopy cover at ≥5 m pixel resolution for many of the largest metropolitan areas in the United States that range in tree canopy cover from 1% to 55% (Nowak et al. 1996; McPherson et al. 2011). This suggests that estimates of tree canopy cover can be collected remotely and may be associated with tree species richness in urban areas based on relationships between stem density and tree canopy cover area (e.g. greater forest cover per ha, higher species richness).

There are a number of high temporal and spatial resolution satellites and sensors that have been used to map forest extent, biomass, and diversity at a global spatial scale (Levin et al. 2007; Hansen et al. 2013). There have been an increasing number of studies that have found significant associations between spectral indices and tree diversity in native forests (Levin et al. 2007; Pettorelli 2013; Gillespie et al. 2014). The normalized difference vegetation index (NDVI) captures the greenness or chlorophyll content of vegetation and photosynthesis processes relating to productivity. This index of plant productivity has been hypothesized to be associated with alpha diversity based on the species-energy or diversity-productivity theory while the standard deviations in NDVI (e.g. nine pixel window) have been associated with diversity based on heterogeneity theories (Evans et al. 2005; Rocchini et al. 2010). The enhanced vegetation index (EVI) also quantifies photosynthetic activity and can resolve important differences in leaf area without being impacted by background soil reflectance (Rocha and Shaver 2009). Vegetation indices from Landsat and MODIS have been able to explain between 20% to 80% of the variance in plant species richness in native ecosystems and this may be the case in urban areas as well (Pettorelli 2013; Gillespie et al. 2014).

Recently airborne lidar has been used to characterize three-dimensional canopy structure for the purposes of modeling biodiversity (Goetz et al. 2007; Bergen et al. 2009). Spatially explicit, high-precision lidar measurements of forest structure from airborne sensors allow for detailed characterization of the forest canopy that was previously not possible using field-based or spaceborne methods. Mean and standard deviation of tree or canopy height have been associated with tree diversity in native forests with taller trees and more heterogeneity in the canopy permitting a wider niche for other tree species to persist (Goetz et al. 2007; Bergen et al. 2009). This may also be the case with tree species richness in urban areas.

This research has three primary objectives. First, we examine patterns of tree species richness, floristic composition, and structure in 1-ha plots in the city of Los Angeles. Second, we examine relationships among climatic, remote sensing metrics, and tree species richness. In particular, we test the hypotheses that tree canopy cover, productivity, and three-dimensional structure are associated with tree species richness in urban areas. Third, we use the statistical relationships between predictor metrics and species richness to predict tree richness across urban landscapes where no ground plot data are available.

Materials and methods

Study area

Los Angeles is located in a coastal plain surrounded by the peninsular and transverse mountain ranges. The climate is Mediterranean with rainfall occurring primarily from November to March. Annual precipitation ranges from 19 to 20 cm near the coast to 75 cm in the mountains. There is a strong coastal to inland gradient in temperature, which ranges from 12 to 20 C° near the coast to 9 to 27 C° in the interior of the basin and valleys. Los Angeles is the second largest metropolitan region in the United States and largest city in a Mediterranean region. Tree densities have rapidly increased from approximately 42 trees per hectare in the 1920's to over 100 trees per ha in 2000 (Gillespie et al. 2012). It is currently estimated that the city of Los Angeles has over 6 million trees and UFORE surveys estimate 210 species occur within the city of Los Angeles (McPherson et al. 2011; Clarke et al. 2013). However, no maps of tree species richness exist for Los Angeles.

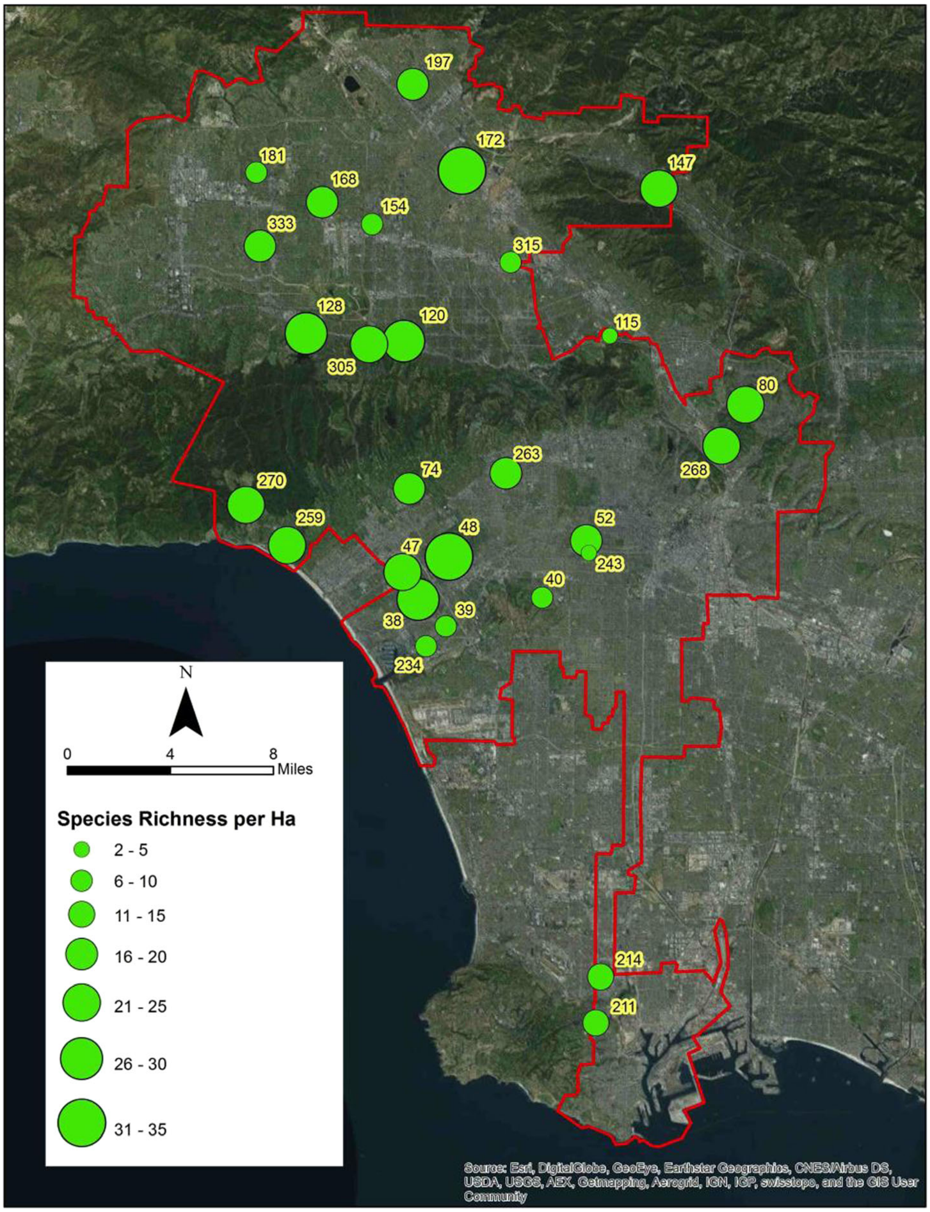
Sampling

We identified 30 locations in the city of Los Angeles using a stratified random-sampling design based on local land cover types in Los Angeles (Nowak and Crane 2002; Clarke et al.

2013) (Fig. 1). The boundaries of each 1-ha plot (100 m by 100 m) were established within Google Earth using UFORE points from Clarke et al. (2013) to define the center of the plot. Tree canopies were digitized in Google Earth as the base layer to identify the extent of tree canopy cover and location of tree species within each 1-ha plot (Fig. 2). Then tree location and species were identified in the field with field surveys undertaken from April 2011 to October 2013. We defined a tree as a woody plant with a single main stem or trunk, two meters or greater in height, and branches above the ground. Every tree with a crown larger than 1 m^2 that was visible in the field and within Google Earth imagery was digitized. We did not include multi-stem shrubs that can cover 1 or 2 m^2 but rarely exceed 2 m in height. Each plot was visited a minimum of twice to identify tree species. Some residents were not present or denied access to their property. Thus, two of the 30 plots were omitted from the analysis (Clarke et al. 2013). All data were converted to vector shape files. This resulted in data on tree species richness, floristic composition, and structure (number of individuals, tree location, and tree canopy cover area) (Appendix 1).

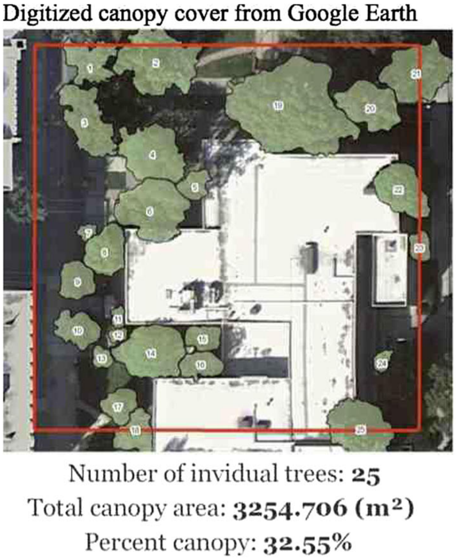
Geographic information systems and remote sensing

Tree species richness from 1-ha plots were compared with metrics hypothesized to be associated with native tree species richness. Climatic metrics on annual temperature and precipitation at a 1 km pixel resolution were collected from



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Fig. 1 Location of 28 1-ha plots with UFORE plot number and tree species richness in the city of Los Angeles



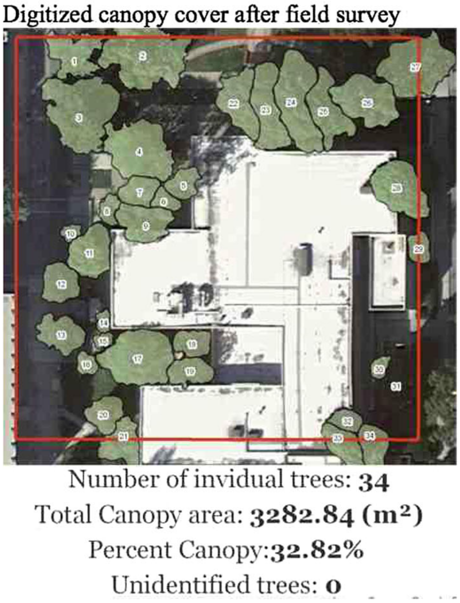


Fig. 2 Quantifying tree canopy cover and individual canopies from Google Earth, and tree canopy cover, individual canopies, and species richness after field surveys at UFORE site 74

WorldClim. High-resolution land cover variables were derived from land cover classifications generated by McPherson et al. (2011). The data were produced from 64 high-resolution QuickBird scenes (2002–2005) and validated with black-and-white aerial imagery (15 cm resolution) from the city of Los Angeles, and 2005 natural color images (91 cm resolution) from the USDA Forest Service. These high-resolution images (60 cm) allowed for a detailed identification of tree canopy cover, grass cover, and impervious surfaces. Landsat 5 imagery from 28 August 2011 was downloaded from Earth Explorer. The date was selected because it corresponds with the peak of the dry season. NDVI values ranging from −1.0 to 1.0 were calculated using the red and infrared bands (band 4 –band 3)/ (band 4 + band 3) from Landsat 5. The locations of the plots were georectified to the image and a single pixel directly over center of the plot was identified. At the plot level, mean and standard deviation of NDVI values were collected for the nine pixels (3 × 3 pixel or 90 m × 90 m) directly over the plot. Vegetation greenness was also quantified using the Moderate Imaging Spectrometer (MODIS) EVI from 16-day 250-m composite products from the EROS datacenter (Jenerette et al. 2013). The mean and standard deviation of EVI was calculated over each 1-ha plot for a 15-year time series from 2000 to 2014. We used airborne lidar to measure the mean vertical canopy height and heterogeneity. Airborne lidar data was acquired from 2006 by the Los Angeles Regional Imagery Acquisition Consortium. Lidar imagery at a 2 m pixel resolution was used to create a digital surface model and a digital elevation model in combination with a digital NDVI layer using 10 cm resolution red and infrared-band images from digital orthophoto quadrangles. Tree canopy extent was defined as any portions of an area in which the surface height model and the digital surface model was greater than 2 m and the normalized difference vegetation index (NDVI) value was greater than 0.1. The mean and standard deviation of tree canopy height was extracted over each 1-ha plot.

Data analysis

We summarized species richness, floristic, and structure data for all plots. All climatic and remote sensing metrics were examined for a normal distribution with a one-sample Kolmogorov-Smirnov test (Appendix 2). Pearson correlation coefficient was used to examine associations between climate and remote sensing metrics. Pearson correlation coefficient, linear regressions, and multi-regressions were used to determine which method best predicted species richness in 1-ha plots for all study sites. Tree species richness maps for Los Angeles were created using regression equations for metrics that examined the most variation in tree species richness. GIS vector data and remote sensing raster data were converted to 1-ha grids for the city of Los Angeles.

Results

Species richness, floristic composition, and structure

There were 1208 individual trees identified in 28 1-ha plots. There were 108 tree species identified in 28 1-ha plots in Los Angeles. Species richness ranged from 2 to 31 species per ha, averaged 17 (± 8.8) species per ha, and was highest in residential areas (mean 21.8, ± 6.2 (Table 1). Stand density ranged from 8 to 90 stems with a mean of 43 (± 19.3) trees per ha. Species density had a J-shaped distribution with the most

Table 1 Tree species richness and structure (density and canopy cover) from 28 1-ha plots in the city of Los Angeles

UFORE Plot # (Land use)	Tree species richness (ha)	Tree density (stems per ha)	Tree cover digitized (m^2)	Tree cover QuickBird (m^2)
48 (R)	31	69	2531	4102
172 (R)	31	69	1503	2047
120 (R)	30	73	1290	2434
38 (R)	28	59	2723	4079
128 (R)	26	46	2450	5333
259 (R)	25	57	1838	2633
270 (R)	24	55	2026	3141
47 (R)	23	44	2007	2600
80 (R)	23	47	2192	3104
147 (I)	22	58	1827	3315
305 (R)	22	35	2133	3385
268 (R)	21	33	1236	1331
197 (R)	20	56	913	1214
333 (R)	20	46	1141	2769
52 (R)	17	42	311	374
74 (I)	17	34	2949	3508
168 (R)	17	90	1545	2175
263 (I)	16	36	1181	1357
214 (M)	13	43	288	219
211 (M)	12	18	781	794
40 (R)	10	39	1925	567
181 (I)	9	28	2218	1502
234 (C)	7	35	461	476
39 (C)	6	15	278	272
154 (C)	6	37	462	906
315 (C)	6	14	459	350
115 (C)	2	21	708	371
243 (T)	2	8	480	1636

R Residential (single family homes), *C* Commercial (business use), *I* Institutional, *M* Multiple family homes, *T* Transportation

common trees in the Arecaceae and Cupressaceae (Table 2) and 50 species observed only once (Fig. 3). There were three species (*Platanus racemosa, Quercus agrifolia, Quercus chrysolepis*) native to Los Angeles and five species (*Chilopsis linearis, Fraxinus uhdei, Juglans hindsii, Pinus radiata, Sequoia sempervirens*) native to the California Floristic Province. The remaining 100 species were from outside the California Floristic Province.

GIS and remote sensing metrics

All GIS and remote sensing metrics had a normal distribution and many metrics were highly correlated (Table 3). Temperature and precipitation were negatively correlated and both climatic metrics were correlated with elevation in Los Angeles. Digitized tree canopy cover from high resolution areal imagery was between 3% and 30% in 1-ha plots (mean 14%, ± 8%). Digitized tree canopy cover was significantly associated with tree canopy cover from QuickBird (r^2 = 0.697), mean NDVI from Landsat (r^2 = 0.752), and EVI 15-year time series from MODIS (r^2 = 0.279). Mean canopy height from lidar was correlated with digitized tree cover and mean NDVI from Landsat (Table 3).

Predictors of tree species richness

None of the climate metrics were associated with tree species richness. However, there was a significant negative association between temperature and stand density (Table 4). Tree canopy cover from QuickBird had the highest correlation with tree species richness, followed by mean NDVI from Landsat, digitized tree canopy cover, and MODIS EVI from 2000 to 2014. Tree canopy cover explained the highest portion of variances (r^2 = 0.540,

Table 2 Tree species composition by density and incidence in 28 1-ha plots in the city of Los Angeles

Family	Scientific name	Density	Incidence
Cupressaceae	*Cupressus sempervirens*	107	11
Arecaceae	*Washingtonia robusta*	95	16
Arecaceae	*Syagrus romanzoffiana*	67	10
Moraceae	*Ficus benjamina*	43	14
Ulmaceae	*Ulmus parvifolia*	40	9
Rutaceae	*Citrus* x *sinensis*	33	13
Platanaceae	*Platanus racemosa*	28	7
Cupressaceae	*Juniperus chinensis*	27	10
Magnoliaceae	*Magnolia grandiflora*	26	10
Ulmaceae	*Betula pendula*	25	5
Myrtaceae	*Melaleuca quinquenervia*	24	4
Rosaceae	*Prunus cerasifera*	22	5
Lythraceae	*Lagerstroemia indica*	20	7
Lauraceae	*Cinnamomum camphora*	16	10
Fabaceae	*Ceratonia siliqua*	15	5
Moraceae	*Ficus microcarpa*	15	7
Bignonaceae	*Jacaranda mimosifolia*	14	8
Sapindaceae	*Cupaniopsis anacardioides*	14	7
Araucariaceae	*Araucaria heterophylla*	14	6
Myrtaceae	*Eucalyptus camaldulensis*	14	3

$P < 0.001$) followed by Landsat mean NDVI ($r^2 = 0.419$, $P < 0.001$) and digitized tree canopy cover in Google Earth ($r^2 = 0.394$, $P < 0.01$) (Fig. 4). Lidar metrics and standard deviations of spectral indices were not associated with tree species richness (Appendix 3). Multiple regressions only slightly improved the amount of variation explained due to high correlation among the best metrics. Tree canopy cover and impervious surface from QuickBird explaining the most variance ($r^2 = 0.582$, $P < 0.001$) followed by tree canopy cover from QuickBird and Landsat mean NDVI ($r^2 = 0.541$, $P < 0.001$). A regression equation [tree species richness =0.0046247 (Tree Canopy Cover m^2) + 8.1087462] was used to map tree species richness from QuickBird tree canopy cover data at 1-ha resolution in the city of Los Angeles (Figs. 5 and 6).

Discussion

There were 108 trees identified to species in a 28 ha plot area in Los Angeles. Estimates of the total number of tree species range from 214 for the city of Los Angeles to 562 tree species for the county of Los Angeles, which may be greater than any other city or metropolitan area in a Mediterranean region (Clarke et al. 2013; Pincetl et al. 2013). Urban tree species richness in residential areas of Los Angeles can be higher than native forests in the California Floristic Province (Barbour et al. 2007). Indeed, 1-ha plots with 30 tree species per ha are higher than native forests in the United States (Currie and Paquin 1987; Qian et al. 2015). Our 28 ha plot area surveyed less than 0.00003% of the area in the city of Los Angeles (10,570 km^2), yet encountered half of all estimated tree species from the city of Los Angeles (Clarke et al. 2013). This suggests that residents select and maintain a diversity of tree species for their property and generally do not prefer homogeneity (Grimm et al. 2008).

A vast majority of species were non-native trees from other regions with few native species outside of the riparian sycamore (*Platanus racemosa*). A vast majority of the native trees did not appear to be relicts from riparian forest or oak woodlands. The most common trees come from a diverse range of floristic regions in temperate and dry lands of Asia, Europe, Australia, and North America. There are

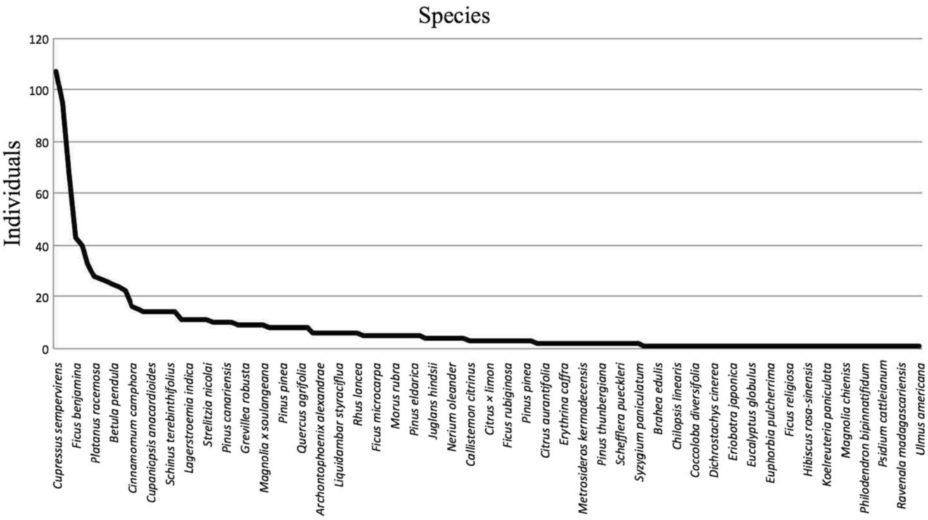


Fig. 3 Species density distribution based on number of individuals in 28 1-ha plots in the city of Los Angeles

Table 3 Correlations among explanatory variables ($n = 28$)

	Temp.	Precip.	Digitized	Quickbird	Landsat	MODIS	Lidar
Temp.	1.00	.	.	.	.	.	.
Precip.	-0.707 (<0.001)	1.00	.	.	.	.	.
Digitized	-0.294 (0.128)	0.381 (0.046)	1.00	.	.	.	.
QuickBird	-0.411 (0.030)	0.504 (0.006)	0.835 (<0.001)	1.00	.	.	.
Landsat	-0.308 (0.118)	0.320 (0.104)	0.868 (<0.001)	0.821 (<0.001)	1.00	.	.
MODIS	0.437 (0.020)	0.366 (0.055)	0.529 (0.004)	0.556 (0.002)	0.813 (<0.001)	1.00	.
Lidar	-0.115 (0.561)	0.157 (0.426)	0.390 (0.040)	0.313 (0.104)	0.380 (0.050)	0.320 (0.097)	1.00
Elevation	-0.771 (<0.001)	0.882 (<0.001)	0.119 (0.309)	0.310 (0.127)	0.133 (0.507)	0.239 (0.220)	0.231 (0.237)

Temp. = mean annual temperature, Precip = mean annual precipitation, Digitized = digitized canopy cover in m^2, QuickBird = canopy cover in m^2, Landsat = mean NDVI in 90 m by 90 m pixel window, MODIS = mean EVI over 14 years, Lidar = mean canopy height, Elevation = elevation in meters. Reported are r-value and *p*-value, in parentheses

two native tree species listed as threatened by the IUCN (*Juglans californica*, *Quercus engelmannii*) in the city of Los Angeles and neither was recorded in 1-ha plots. This suggests that native species richness has been reduced in Los Angeles similar to other urban areas and ecosystem reconstruction is required to achieve a target of 10% native cover in Los Angeles (Clarkson et al. 2007; Grimm et al. 2008). It may be appropriate to introduce these threatened and native tree species to residential areas and institutional areas (Kowarik 2011).

Table 4 Pearson correlation coefficient between climatic and remote sensing metrics and tree species richness and density from 28 1-ha plots in the city of Los Angeles

Metrics	Species richness	Stem density
Climate		
Temperature	-0.310	-0.415*
Precipitation	0.344	0.336
High resolution imagery		
Digitized canopy cover	0.629**	0.423*
QuickBird		
Tree canopy cover	0.735**	0.486*
Impervious surface	-0.681**	-0.470*
Grass cover	0.142	0.000
Landsat		
NDVI mean	0.648**	0.421*
NDVI sd	0.071	-0.115
MODIS time series		
EVI mean	0.384*	0.217
EVI sd	-0.043	0.080
Lidar		
Canopy height mean	0.040	-0.143
Canopy height sd	0.137	-0.049

* = $P < 0.05$, ** = $P < 0.01$

Urban forests are almost completely driven by anthropogenic factors and there was almost no natural recruitment observed in our surveys. However, urban forests exhibit species density distributions similar to tropical forests that contain a large proportion of rare species (e.g. 1 or 2 occurrences). This should also be the case when examining 1-ha plot data for other urban forests in the California Floristic Province (e.g. San Diego, Santa Barbara, San Francisco, Sacramento) and other Mediterranean regions (e.g. Barcelona, Rome, Athens).

Predicting species richness

Like many forests around the world, the number of stems per unit area was significantly associated with species richness (Conduit et al. 1996; Clarke et al. 2013). Indeed, the tree canopy area in Los Angeles is similar to native forest and woodland ecosystems, and when the canopies are digitized, they provide a metric similar to the number of stems. However, the tree density can only explain 58% of the variance in tree species richness in Los Angeles.

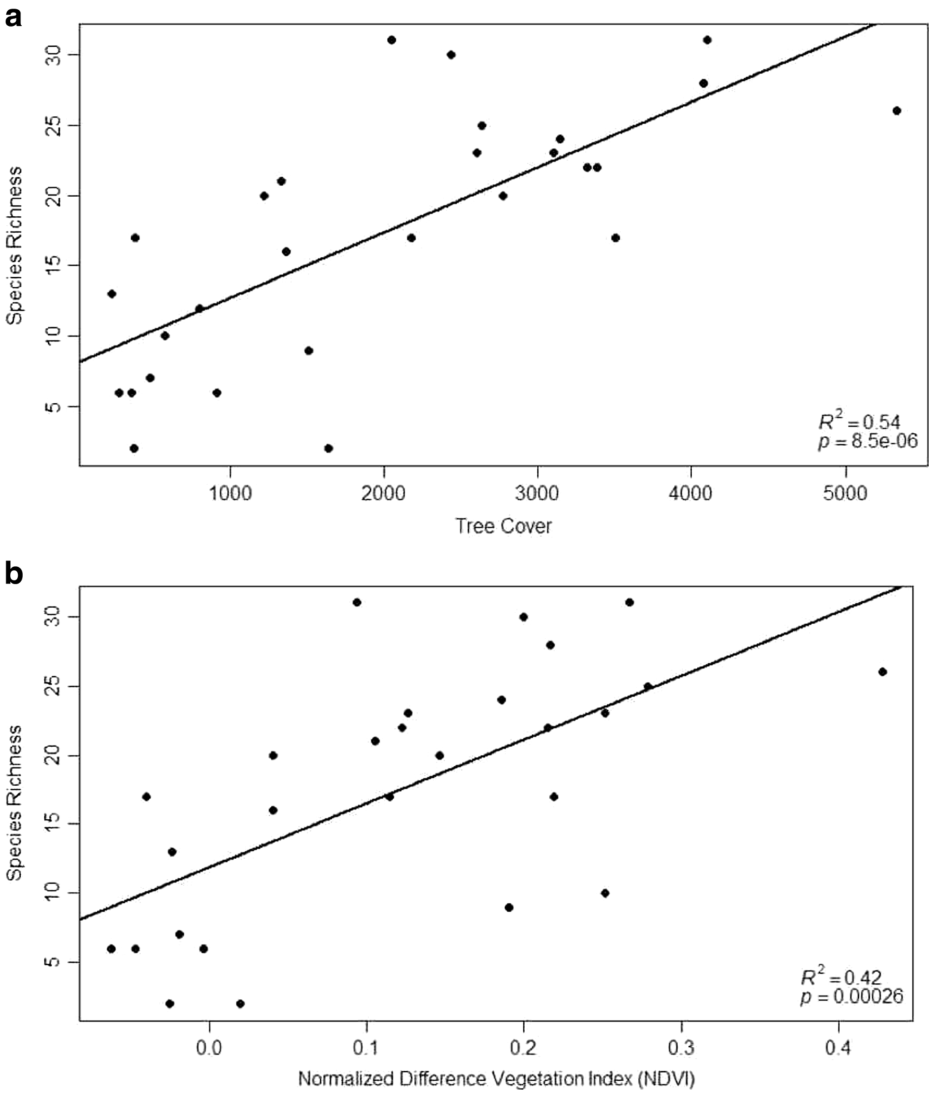


Fig. 4 Regressions between tree species richness and tree canopy cover (ha) from QuickBird (**a**) and Landsat NDVI (**b**)

It is interesting to note that our highest resolution data of digitized tree canopy cover from Google Earth did not perform better than QuickBird or Landsat NDVI. Other remote sensing studies have noted that the highest spatial resolution data is not always the best predictor of species richness across a landscape (Levin et al. 2007). There have been an increasing number of cities that have collected tree canopy cover data with half of the largest 50 cities in the United States producing high resolution maps on tree canopy cover (McPherson et al. 2011). Our results suggest that tree species richness maps may now be created and tested for urban areas based on tree canopy cover per ha.

Vegetation indices from Landsat can predict approximately 40% of the variation in tree species richness in Los Angeles. Mean NDVI and EVI had the highest correlation with species richness, however, the standard deviation as a measure of heterogeneity was not associated with species richness (Rocchini et al. 2010). It may be the case that urban forests are more structurally stable or maintained than native forests, thus the spectral heterogeneity as measured by standard deviations of the urban forest is not as important as productivity. EVI from MODIS had lower yet significant correlations with species richness which may be due to larger pixel size (e.g. 250 m by 250 m) than plot size (e.g. 100 m by 100 m) and the time series nature of the data. Lidar metrics was not significantly associated with tree species richness. This suggests that mean and standard deviations in tree height may not be associated with tree species richness in urban areas and vertical structure is independent of tree diversity in urban landscapes.

Species richness maps

Species richness maps were similar for QuickBird and Landsat for the city of Los Angeles. These maps also

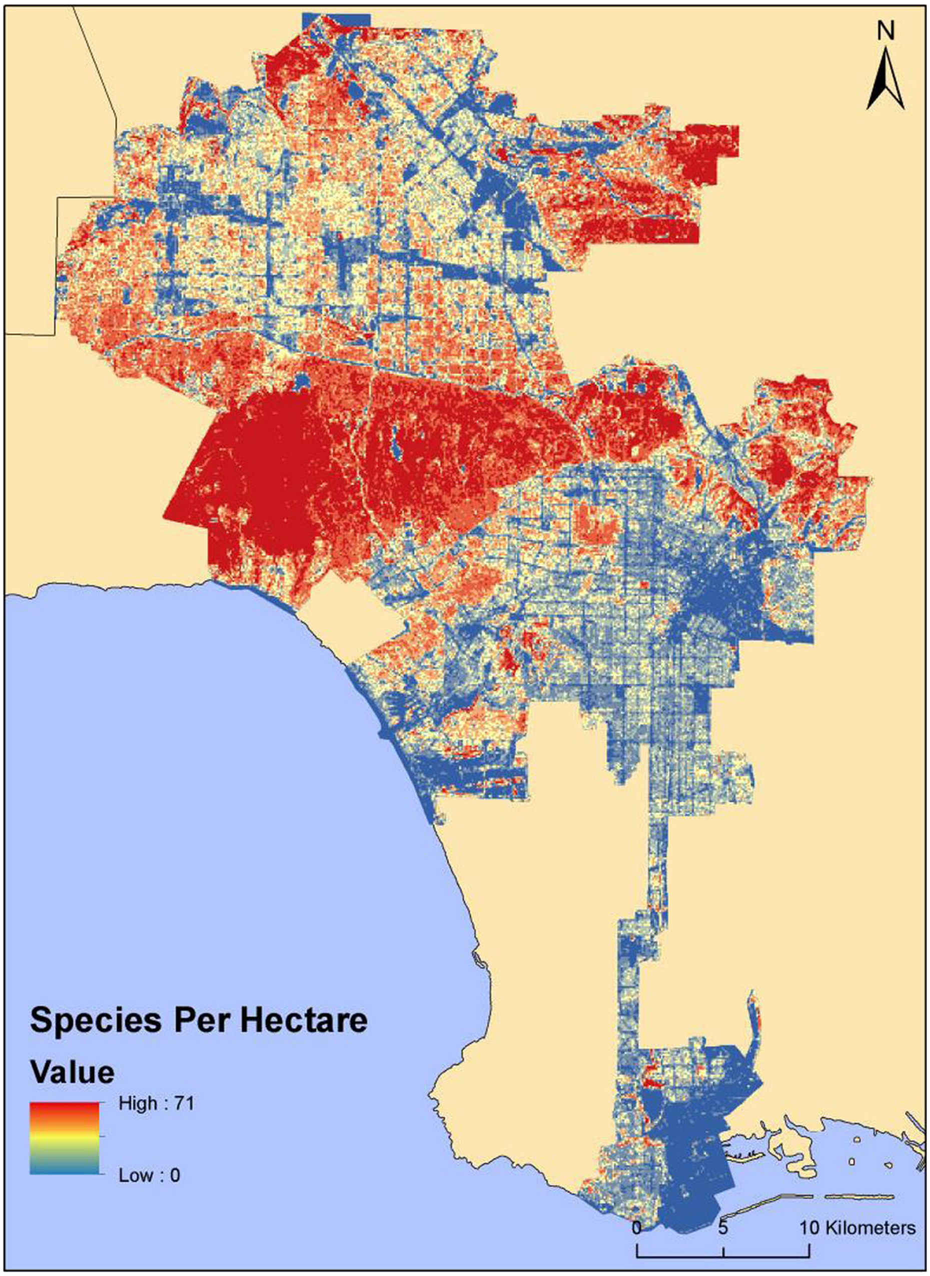


Fig. 5 Tree species richness map for the city of Los Angeles from Quick Bird

identified potential high diversity areas or hotspots when set to identify urban forests with 25 or more tree species. Indeed, neighborhoods in Bel Air, Sherman Oaks, and the Hollywood Hills were identified as some of the most diverse areas in Los Angeles. Low diversity areas, or coldspots, can be identified in urban areas and it may be appropriate for city planners and non-profit organizations to focus on these regions and provide residents with a diversity of tree choices that may be of cultural, economic, or aesthetic interest and include a diversity of functional traits (Jenerette et al. 2013). It may not only be important to increase tree canopy cover in these areas but also to increase diversity for the benefits associated with tree diversity (e.g. cultural economic, aesthetic) and the development of an urban forest legacy in communities (Hope et al. 2003; Clarke et al. 2013; Jenerette et al. 2013).

Management implications

There are a number of reasons why it is important to map tree species richness in urban areas. First, it can provide planners, scientists, and the general public with high spatial resolution (1-ha) data on predicted species richness that are important for conserving biodiversity in cities

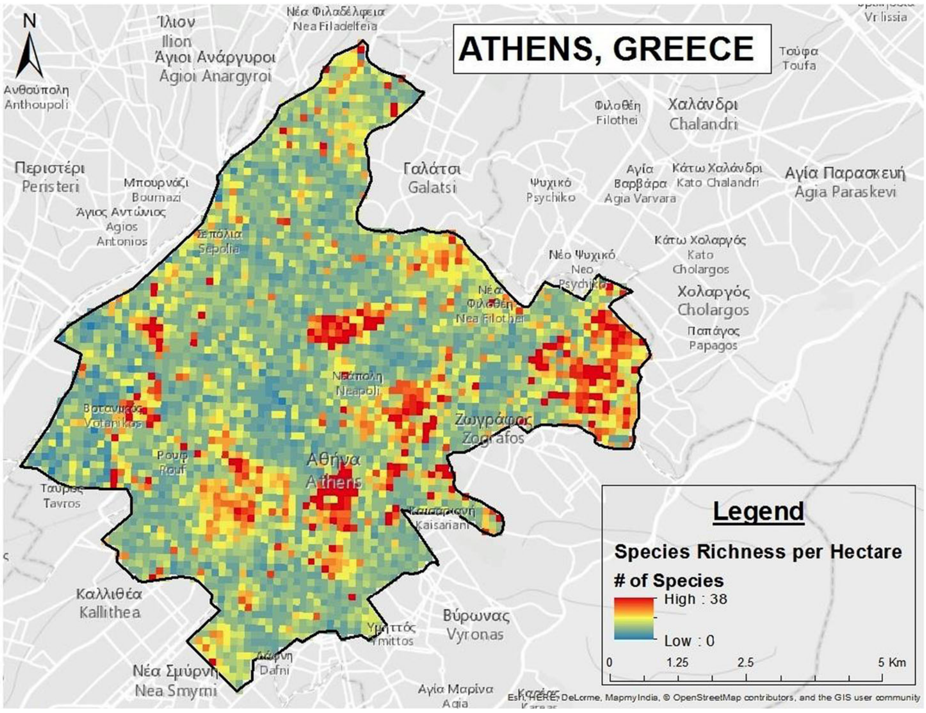


Fig. 6 Predicted tree species richness from 2011 Landsat TM at 1 ha resolution for Athens, Greece based on city of Los Angeles regression equation

(Godefroid and Koedam 2007; Grimm et al. 2008; Tzoulas and James 2009). Indeed, due to the foundational importance of forest structure to levels of biodiversity, tree species richness would be expected to mirror diversity in other taxa such as mammals, birds, and insects (Kowarik 2011). Second, both tree canopy cover and Landsat NDVI can be used to assess the success of such tree planting programs in both communities and cities. Maps of tree species richness can be created for all cities using Landsat NDVI and the regression equation from this study. We expect that the maps at 1-ha will only explain up to 40% of the variance in tree species richness, but this is a significant improvement over no spatially explicit species richness maps for urban areas. These maps can be used to identify hotspots and coldspots of diversity in Los Angeles, and other cities within Mediterranean regions such as Athens, Rome, and Barcelona (Fig. 5; Appendix 4). However, the regression equation from Los Angeles needs to be tested in other Mediterranean cities using 1-ha plot data and thus our regression equation and maps currently provide only a first order assessment. Time series analyses of patterns of afforestation and changes in urban tree species richness can also be created using Landsat 5 going back to 1984. This should not only show changes in tree canopy cover, but changes in tree species richness over time. When 1-ha field surveys are undertaken, they can be used to calibrate results with tree canopy cover or NDVI from Landsat and further improve estimates in tree species richness patterns in cities. These 1-ha plots can complement more extensive UFORE plot methods which cover only 0.04 ha and had no or lower correlations with remote sensing metrics of species richness due to the small plot sizes. Furthermore, results can help in monitoring of tree planting policies in cities, and assist program development.

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