J Environ Stud Sci (2014) 4:250–262
DOI 10.1007/s13412-014-0176-x

Urban environmental stewardship and changes in vegetative cover and building footprint in New York City neighborhoods (2000–2010)

Dexter H. Locke · Kristen L. King · Erika S. Svendsen · Lindsay K. Campbell · Christopher Small · Nancy F. Sonti · Dana R. Fisher · Jacqueline W. T. Lu

Published online: 29 July 2014

Abstract This study explores the connections between vegetation cover change, environmental stewardship, and building footprint change in New York City neighborhoods from the years 2000 to 2010. We use a mixed-methods multidisciplinary approach to analyze spatially explicit social and ecological data. Most neighborhoods lost vegetation during the study period. Neighborhoods that gained vegetation tended to have, on average, more stewardship groups. We contextualize the ways in which stewardship groups lead to the observed decadal- and neighborhood-scale changes in urban vegetation cover. This multidisciplinary synthesis combines the strengths of quantitative data to identify patterns, and qualitative data to understand process. While we recognize the complexity of cities and the potential confounding factors, this exploratory analysis uses sound theory and data from a mixed methodological approach to show the role of urban environmental stewardship in affecting the New York City landscape.

Keywords Urban ecology · Remote sensing · Urban stewardship · STEW-MAP · Mixed methods · Vegetation cover

D. H. Locke (✉)
Graduate School of Geography, Clark University, 950 Main Street, Worcester, MA 01610-1477, USA
e-mail: dexter.locke@gmail.com

K. L. King
Forestry, Horticulture, & Natural Resources, New York City Department of Parks and Recreation, 1234 Fifth Avenue, New York, NY 10029, USA

E. S. Svendsen · L. K. Campbell · N. F. Sonti
USDA Forest Service Northern Research Station, NYC Urban Field Station, 431 Walter Reed Road, Fort Totten Park, Bayside, NY 11360, USA

C. Small
Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964-8000, USA

D. R. Fisher
Department of Sociology, University of Maryland, 2112 Art-Sociology, College Park, MD 20742, USA

J. W. T. Lu
Forestry, Horticulture & Natural Resources, New York City Department of Parks & Recreation, Olmsted Center, Flushing Meadow Corona Park, Flushing, New York 11368, USA

Introduction

New York City's five boroughs are not often thought of as highly vegetated. However, recent estimates derived from high-resolution imagery and other remotely sensed data, including Light Detection and Ranging (LiDAR), show that approximately 20 % of the City's land area is beneath the urban tree canopy, and an additional 18 % is either grass or shrub (MacFaden et al. 2012; O'Neil-Dunne 2012). The benefits of this urban vegetation are well documented. In densely populated areas, trees, shrubs, and grass can provide important services such as microclimate regulation (Rosenfeld et al. 1998; Nowak 2002; Nowak et al. 2007), air quality improvement (Nowak et al. 1998; Beckett et al. 2000), storm water mitigation (Beattie et al. 2000; Nowak et al. 2007), carbon storage (McPherson et al. 1994; Nowak and Crane 2002; Kovacs et al. 2013), habitat provision (Fernandez-Juricic 2000; Rudd et al. 2002), and socio-psychological benefits (Dwyer et al. 1992; Hartig et al. 1991; Kuo and Sullivan 2001). In 2007, New York City launched Million Trees NYC, an ambitious campaign to plant one million trees, in part a direct response to these documented ecosystem services (Campbell 2014).

Despite large scale planting efforts like Million Trees NYC, a recent study found that 17 of 20 cities experienced a decline in vegetation, including an estimated 1.2 % decline in tree cover from years 2004 to 2009 in New York City (Nowak and Greenfield 2012). Remote sensing techniques can reveal temporal and spatial changes in the provisioning of urban tree canopy benefits. Inequitable distribution of such ecosystem services has implications for policy or community-based action around environmental quality and justice. This paper explores how stewardship groups contribute to shaping critically important urban natural resources.

Cities are complex, multi-scalar, socio-ecological systems. As such, understanding the relationship between vegetation abundance and stewardship activity within a massive urban ecosystem such as New York City necessitates the application of a multidisciplinary, spatio-temporal framework. The dynamic interactions between the urban forest and its stewards can be envisioned as an exchange of ecosystem services and stewardship efforts. Other mediating factors, such as building construction and changing land uses, inevitably play a role too. A variety of stewardship organizations, including community groups and nonprofits, as well as government agencies, care for and manage the urban forest, while the forest provides benefits to urban residents. In this paper, we seek to address the following questions: Accounting for changes in building footprint area, is there a relationship between the number of active stewardship groups in a neighborhood and the trajectory of vegetation change from 2000 to 2010? How do civic stewardship groups impact the abundance and distribution of vegetation at the neighborhood scale, if at all? In neighborhoods exemplifying outlying patterns of vegetation and building footprint change, we look qualitatively at civic organizations' activities and public park management records to understand how public and civic stewards alter their environments. Through a triangulation of remotely sensed and Geographic Information System (GIS) data, surveys and interviews, and park records, this study explores the connections between vegetation change, building development, and urban environmental stewardship in New York City's neighborhoods.

Motivations

Some civic environmental stewardship groups conserve and maintain existing resources, while others work to create access to waterfronts, or build new public spaces (Fisher et al. 2012). As urban ecosystems evolve over time, so does the rich fabric of civic stewardship activity (Connolly et al. 2013). Research in six major northeastern US cities reveals the diverse scope and complexity of environmental stewardship organizations regarding site types, biophysical aims, and ecological impacts, and with varying levels of volunteerism and salaried compensation (Svendsen and Campbell 2008). Among the 135 groups surveyed throughout the six cities, 34.5 % focused their efforts on the stewardship of designated open spaces including parks, playgrounds, and natural areas—urban places where vegetation (trees, grass, and shrubs) is often present.

A more detailed survey of stewardship activities in New York City was conducted in 2007 as part of the Stewardship Mapping and Assessment Project (STEW-MAP), covering organizational characteristics, stewardship activities, and the connections between stewardship groups. Data were collected from environmental stewardship groups, defined as organizations that actively conserve, manage, monitor, advocate for, or educate those in their communities about their local environments (Fisher et al. 2012). The mission statements of stewardship groups reveal the specific tasks that these groups perform in hopes of affecting their local environment. In many cases, they involve making changes to vegetation cover across various property jurisdictions and physical site types. For example, the Riverside Park Native Plant Project aims to "establish a community of plants native to the Hudson Valley" in order to improve wildlife habitat. Similarly, the New York Tree Trust was established to "protect, preserve, and enhance New York City's street, park, and forest trees." Civic stewardship organizations protect, enhance, and help establish greener areas in New York City. But the extent to which these efforts contribute to observable changes in vegetation abundance at the decadal scale remains understudied.

Similar civic environmental stewardship research is also underway in other North American cities. The abundance of stewardship groups and the number of network connections between them is significantly negatively correlated with the percentage of tree canopy in Baltimore neighborhoods, while there is no correlation between the number of organizations or their network characteristics and the abundance of tree canopy in Seattle neighborhoods (Romolini et al. 2013). In this paper, we examine changes in greening as it corresponds to stewardship group activity in New York City.

Methods

Our analyses apply the extensive-intensive framework from Grove and others (2013), using a mixed-methods approach that incorporates both social and ecological data. The analyses were carried out in four stages. First, Spectral Mixture Analysis (SMA) was used to derive vegetation maps for years 2000 and 2010. Next, building footprints from 2001 and 2010 and vegetation change were summarized within-neighborhood boundaries in a GIS. Then, these layers were analyzed in conjunction with spatially explicit data about environmental stewardship group activity. Finally, in the fourth stage, qualitative data from interviews with local environmental stewards were analyzed to contextualize the relationships found between stewardship group presence and changes in vegetation and building footprint. In this way, we integrate environmental data (vegetation and building footprint change) with social data (surveys and interviews), which contextualize the ways in which social actors impact their local environment (for more detail on this methodological approach, see Grove et al. 2013). Each of the four phases is described in greater detail below.

Spectral mixture analysis

Optical sensors onboard the Landsat satellites provide synoptic, retrospective estimates of the amount and location of vegetation in New York City. Made publically available by the U.S. Geological Survey, more than 300 cloud-free images of optical radiance and surface temperature from 1984 to the present provide a basis for our mapping of vegetation change in New York City. We use SMA to estimate the abundance of vegetation contributing to the aggregate radiance signal measured by the sensors on Landsats 4, 5, and 7. SMA represents the heterogeneous mosaic of land cover within each pixel as a linear mixture of spectrally pure end members representing specific land cover components (Adams et al. 1986). Spectral mixture models are well-suited to mapping urban vegetation because they can quantify abundance and changes in vegetation at scales finer than the 30 m resolution of the TM and ETM+sensors (e.g., Small 2001; Tooke et al. 2009; Van de Voorde et al. 2008). Inversion of the linear mixture model yields estimates of the areal fraction of each end member (or spectrally pure reference signature) present within each mixed pixel. The resulting end member fraction maps provide quantitative estimates of end member materials such as vegetation and substrate as well as shadow (see Small 2001 and Small and Lu 2006 for complete methods). For many applications, continuous fraction maps are preferable to discrete thematic classifications (e.g., Anderson et al. 1976; see also Cadenasso et al. 2007 for limits in urban areas). The main advantages of fraction maps are the accommodation of multi scale heterogeneity, the consistency with the physical components of the urban mosaic, and the relative ease of quantitative validation. Despite the 30-m spatial resolution provided by the Landsat TM and ETM+sensors, the inherently scalable spectral mixture model has proved effective in detecting subpixel vegetation as verified by vicarious validation with higher resolution imagery in New York City (Small and Lu 2006).

We estimated changes in vegetation abundance using inter calibrated Landsat 5 images collected under similar illumination conditions on August 24, 2000 and September 5, 2010. Both images were calibrated to exoatmospheric reflectance and unmixed with a three end member linear mixture model using global spectral end members from Small (2004). Using calibrated reflectance acquired under clear sky conditions and common spectral end members minimizes extraneous variability to the extent possible. The mean change in vegetation fraction for all 876,542 pixels in the five boroughs of New York City was 0.023 suggesting less than 3 % bias in the change estimates.

Vicarious validation of Landsat-derived vegetation fraction estimates with a near-simultaneous acquisition of high-resolution (2 m) Worldview-2 imagery on April 23 and May 1, 2010 illustrate the linear scaling of the subpixel vegetation abundance estimates used in this study (Fig. 1). The small downward bias of the Landsat-derived vegetation fractions (−0.01, sd of fraction difference distribution=0.05) results from the use of local spectral end members in the Worldview-2 estimates compared to the global spectral end members used for the Landsat estimates. Because the same global end members were used to unmix both Landsat images, this bias does not affect our change estimates. Despite the small bias, the linearity of the plot confirms the linearity of the scaling from 2 to 30 m.

Due to measurement errors associated with detecting small amounts of vegetation using the SMA methods, those pixels containing less than 5 % vegetation were excluded from analysis. However, values of zero were retained because they consistently measured the presence of open water within-neighborhood waterways. Raster layers depicting the percent of the each pixel's coverage area consisting of illuminated, nadir-visible vegetation were derived from pixels with absolute changes greater than 5 % between 2000 and 2010.

Environmental stewardship group surveys

The spatial database of stewardship activity was developed as part of the Stewardship Mapping and Assessment Project (STEW-MAP). In order to develop the citywide sample of civic stewardship organizations, a snowball sampling methodology was used. City- and borough-wide nonprofits and government agencies were asked to provide a list of organizational partners who work on environmental issues, and those groups continued to suggest additional data providing organizations until saturation was reached. The sampling frame required that organizations consist of more than one individual, work within New York City's five boroughs, and have a valid mailing or e-mail address (for more detail, see Fisher et al. 2012). Public agencies and quasi-governmental entities were removed from the sample, because STEW-MAP examined the role of civil society groups working as environmental stewards (Fisher et al. 2012). Following this approach, 2,596 civic groups were surveyed and a total of 506 groups responded, representing a response rate of 18.3 %. This response rate is within the common range for mail-in and Internet surveys of organizations (for a full discussion, see Hager et al. 2003).

The assessment was based on the previous multi-city pilot study (Svendsen and Campbell 2008) and was designed to collect information on elements of organizational structure including number of members, site types, and budgets; stewardship geographic footprint (where the group works); and social networks, in terms of organizations with which each

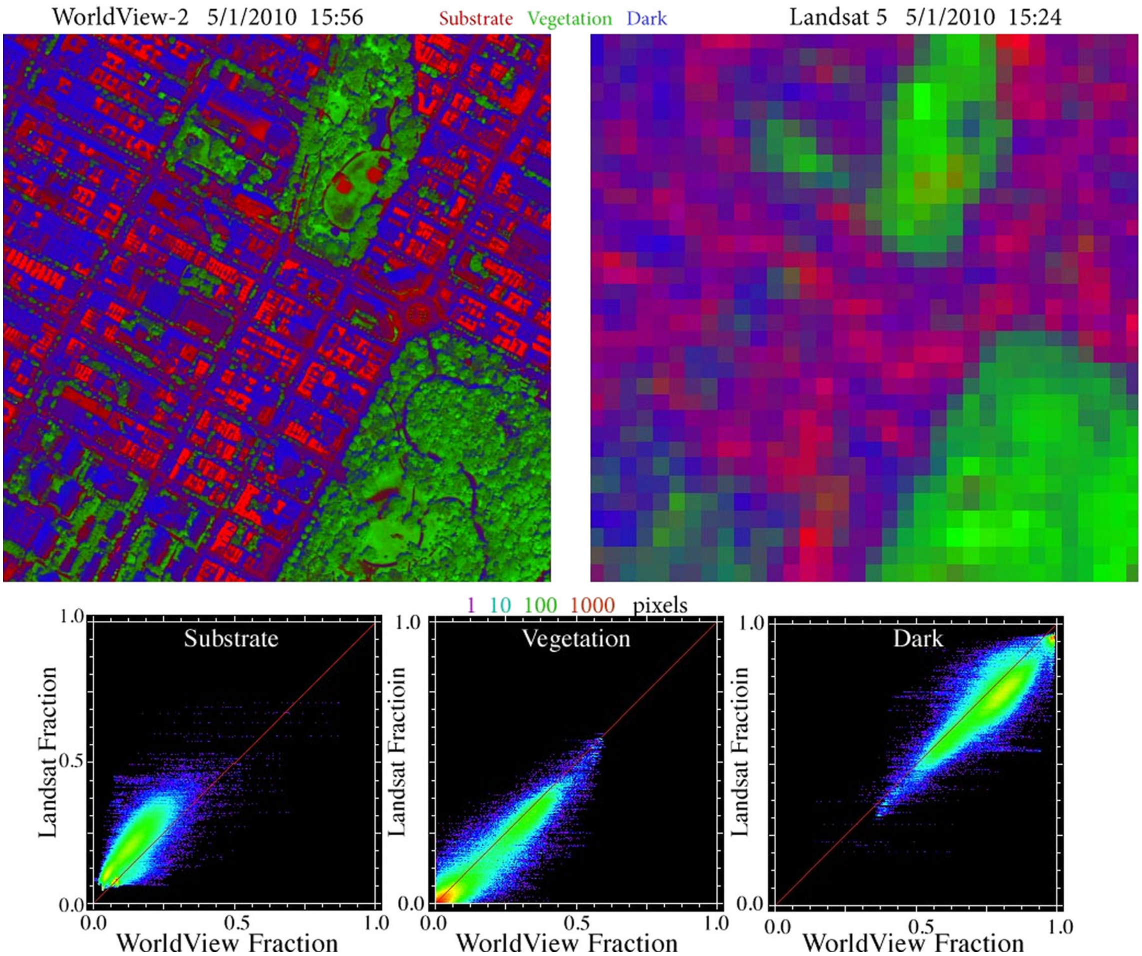


Fig. 1 Vicarious validation for upper Manhattan. Full resolution examples illustrate vegetation fractions as resolved by each sensor. Landsat TM imaginary was calibrated to top of atmosphere reflectance and unmixed with global end members. World view-2 imagery was to top of atmosphere reflectance and unmixed with image end mends. Landsat and Worldwide have very different substrate end members so agreement is not as close as for vegetation and dark surfaces. The bias for the Landsat-derived vegetation fraction is −0.01 and the standard deviation of the fraction difference distribution is 0.05; most likely resulting from spatial co-registration. Fraction distributions and statistics are from a much larger area of upper Manhattan including all of central park

group collaborates. Complete assessment and methodological details can be found in Fisher et al. (2012) and the full survey instrument is available at http://www.stewmap.net/wp-content/uploads/2014/05/StewMap.Survey_NYC.pdf. Data were collected over the course of 6 months in 2007 in accordance with Columbia University's IRB protocol #IRB-AAAC3985. Data regarding the physical boundaries of where each group works were collected as part of this survey of the stewardship organizations. These data were digitized into polygons in ArcGIS 9.3.1 (ESRI 2009).

Public park records and semi-structured interviews with civic environmental stewardship groups

During the summer of 2010, open-ended semi-structured interviews were conducted with the directors of the 14 most connected civic groups that serve as 'bridge organizations' in the stewardship network in New York City. We identified bridge organizations as those civic groups that were at least two standard deviations above the mean in terms of in-degree ties and betweenness. In-degree ties are the number of times a group is listed as partners by other groups in the network; betweenness is a social network analysis statistic that measures the extent to which a point lies between other points in a network graph (Scott 2000). The interviews focused on organizational history as well as the development of the environmental stewardship network and how stewardship activities have changed over time and lasted about 1 hour (full details about the social network analysis and interview methodology are described in Connolly et al. (2013). Information from these interviews about the history of stewardship during the 2000s provide data included in the results section of this paper.

Citywide civic stewardship data was supplemented with data about public interventions in the case study neighborhoods, described in the results below. Details regarding the management of open space in New York City come from the first-hand knowledge of several of the authors, who are employees of the New York City Department of Parks & Recreation. This experiential knowledge was reinforced using ortho imagery of transformed parks, informal interviews with park managers, and parks archives and management records to construct a history of park development and management in the three selected neighborhoods from 2000 to 2010.

Multidisciplinary data integration using GIS

To inform PlaNYC, the City's long-term sustainability plan (The City of New York 2007), the New York City Department of City Planning created a set of neighborhood boundaries by aggregating entire census tracts for projecting populations at a small area level, known as Neighborhood Projection Areas. These boundaries generally align with vernacular notions of New York City neighborhoods, and are thus valuable from a social perspective. Because they were not originally intended for uses other than population projection, some "neighborhoods" were merged with others or split from others in a way that is not conducive to this analysis or a clear understanding of neighborhood boundaries in New York City. Because of this, the projection areas were slightly modified prior to these analyses. Specific examples of this processing include recombining the spatially noncontiguous but administratively linked island polygons in the Jamaica Bay wetland area into a single unit; splitting parks and cemeteries into separate polygons when they were noncontiguous and politically distinct, such as Riverside and Central Parks; and separating the natural area of Pralls Island, which has no human population, from a nearby residential neighborhood. Next, spurious slivers with too few pixels for analysis were manually deleted or merged into an adjacent polygon.

The 2000 and 2010 rasters created via SMA from the Landsat data were each summarized to the neighborhood boundaries, resulting in percent vegetation for each neighborhood for each year. Subtracting 2000 percent vegetation from 2010 percent vegetation resulted in a final map with the percent vegetation change for each neighborhood. The spatial join tool in ArcGIS 9.3.1 (ESRI 2009) was used to enumerate the number of active environmental stewardship organizations within each neighborhood boundary.

Building footprint area data from 2001 to 2010 from New York City's GIS base map (NYC Department of Information Technology and Telecommunications) were aggregated to each neighborhood using the intersect tool and subsequent summary statistics in ArcGIS 9.3.1. Subtracting the year 2001 building area from the 2010 area by neighborhood yielded the change in percentage area of buildings so that the role of construction could be explored.

We explored interactions between stewards and their environment through analysis of the self-described geographic boundaries or spatial footprint of stewardship groups gathered in 2007, along with vegetation data derived from available cloud-free Landsat imagery in August 2000 and 2010, as well as building footprint change from years 2001 to 2010 within 243 neighborhoods in New York City. Although stewardship regimes are in a constant state of flux, the cross-sectional stewardship data were collected in 2007 and may be considered reflective of a particular state of environmental stewardship in 2006, approximately the midpoint of the decade of interest. All statistical analyses were performed in PASW Statistics 18 (IBM 2009).

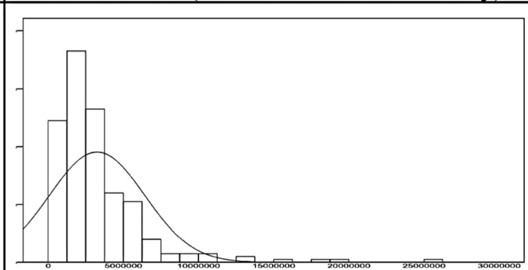
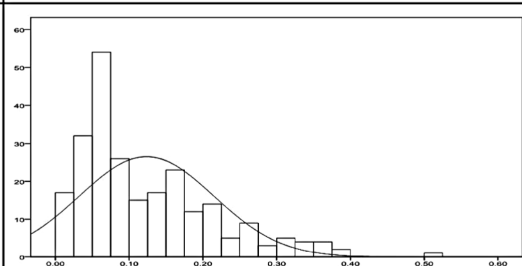
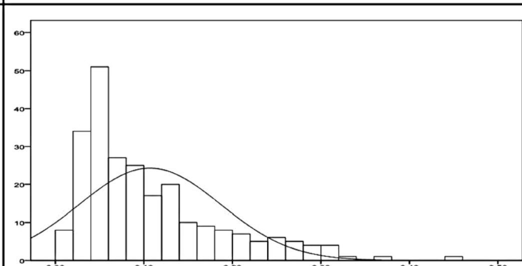
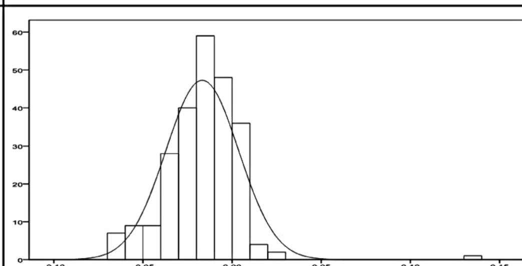
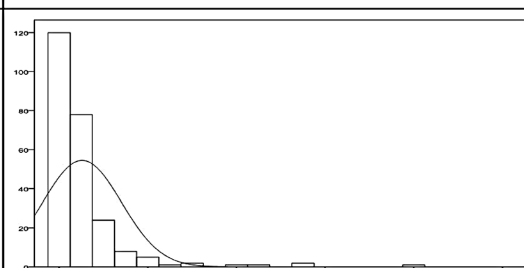
Results

Citywide patterns of change

The descriptive statistics show that, on average, there was very little vegetation change at the neighborhood scale in New York City between 2000 and 2010 (Table 1), but those changes that did occur during that decade consisted of minor to moderate losses. At the neighborhood scale, only 43 of the 243 neighborhoods saw an increase in vegetation over the study period (Fig. 2a, b), with the largest increase observed attributable to the creation of the new Brooklyn Bridge Park (+13.2 %) over previously nonvegetated piers. Most increases in vegetation occurred in Manhattan, while all neighborhoods in Staten Island and the majority of neighborhoods in the Bronx, Brooklyn, and Queens lost vegetation. Soundview Park in the Bronx lost the most vegetation of all study areas, with a decrease of approximately 7 % between 2000 and 2010.

We find no evidence for a linear relationship between the amount of vegetation change from year 2000 to 2010 and the number of active stewardship organizations in each neighborhood (Fig. 3). However, there is a statistically significant difference in the number of stewardship groups for neighborhoods losing and gaining vegetation (Mann–Whitney U= 2292.5, n_1=200, n_2=43, p<0.0001). In other words, most neighborhoods lost a relatively small amount of vegetation, but those neighborhoods that experienced an increase in vegetation tended to have more active stewardship groups. When combining vegetation increase or decrease with building increase or decrease, each neighborhood falls within one of four categorical combinations (Fig. 2d). Figure 4 plots these neighborhoods along two axes, creating four quadrants: vegetation increase with building increase (quadrant I), vegetation increase with building decrease (quadrant II), vegetation decrease with building decrease (quadrant III), and vegetation decrease with building increase (quadrant IV). The scatter plot illustrates that, overall, most neighborhoods had little to no building footprint change and a slight decrease in vegetation. There are 33 neighborhoods exhibiting an increase in

Table 1 Mean, median, variance, and distribution curves for vegetation and stewardship measures

	Mean	Median	Variance	Distribution (with normal curve overlay)
Neighborhood Area (sq. km)	3253.62	2457.42	1.01E+10	
Vegetation fraction (2000)	0.124	0.093	0.008	
Vegetation fraction (2010)	0.107	0.081	0.006	
Vegetation change (2000-2010)	-0.017	-0.015	0	
no. active stewardship groups (2007)	5.19	3.00	79.135	

vegetation and a loss in building footprint via the development of major waterfront parks (see quadrant II). In addition, 103 neighborhoods exhibit the seemingly unusual pattern of decreasing vegetation and decreasing building footprint (see quadrant III), and 93 neighborhoods in quadrant IV exhibit a traditional development pattern of decreasing vegetation with new building construction. Fourteen neighborhoods exhibited an increase in both building footprint and vegetation (quadrant I), but all changes were extremely minor in these few cases.

Manhattan neighborhoods experienced greater increases in greening during our study period than any of the other four boroughs, and it is the only borough with an overall positive vegetation trajectory. An analysis of change in building footprint across all five boroughs between 2001 and 2010 reveals

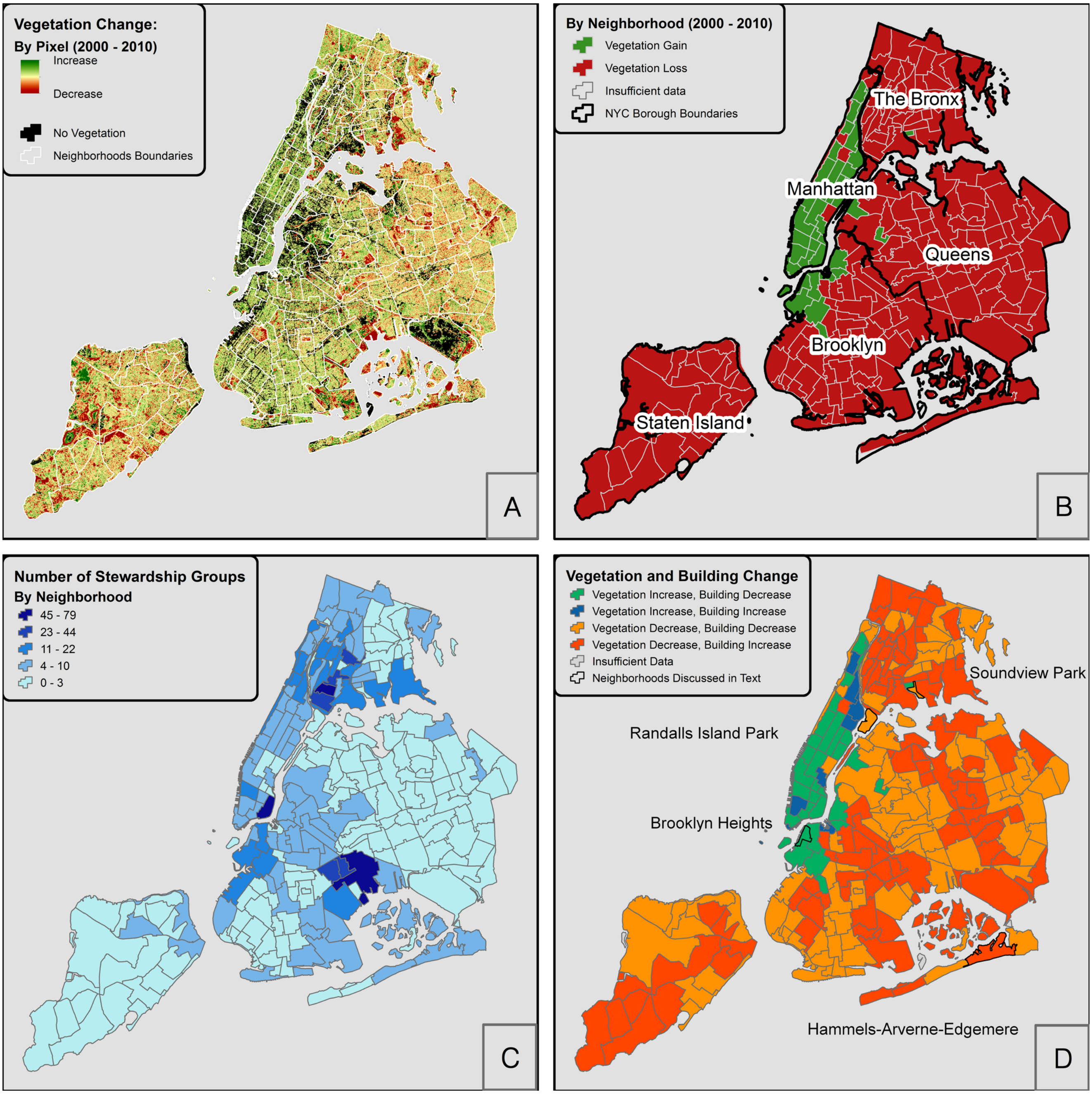


Fig. 2 **a** Vegetation change in New York City (2000–2010). Resolution=30 m. **b** Trajectories of vegetation change in NYC neighborhoods (2000–2010). **c** Stewardship activity in New York City neighborhoods. **d** Vegetation and building change across New York City neighborhoods. The tri-temporal vegetation change map and stewardship data can be queried interactively at www.LDEO.columbia.edu/~small/dNYC

that neighborhoods whose building footprint increased lost vegetation when compared to those that saw a decrease in buildings (Mann–Whitney $U=5526.0$, $n_1=136$, $n_2=103$, $p<0.01$).

Patterns of neighborhood change: case studies

In the following section, we overlay our stewardship data across these four categories of neighborhoods to assess the relationship between greening, stewardship, and infrastructure. Greening neighborhoods have more stewards regardless of changes in building footprint. However, neighborhoods experiencing a loss of vegetation and an increase in building footprint (quadrant IV) have a higher number of stewardship groups than neighborhoods with a loss of vegetation and building footprint (quadrant III) (Kruskal-Wallis test: $H=22.1$, 2 df, $p<0.0001$).

The STEW-MAP database, combined with public records from the New York City Department of Parks & Recreation and data from interviews with organizational representatives,

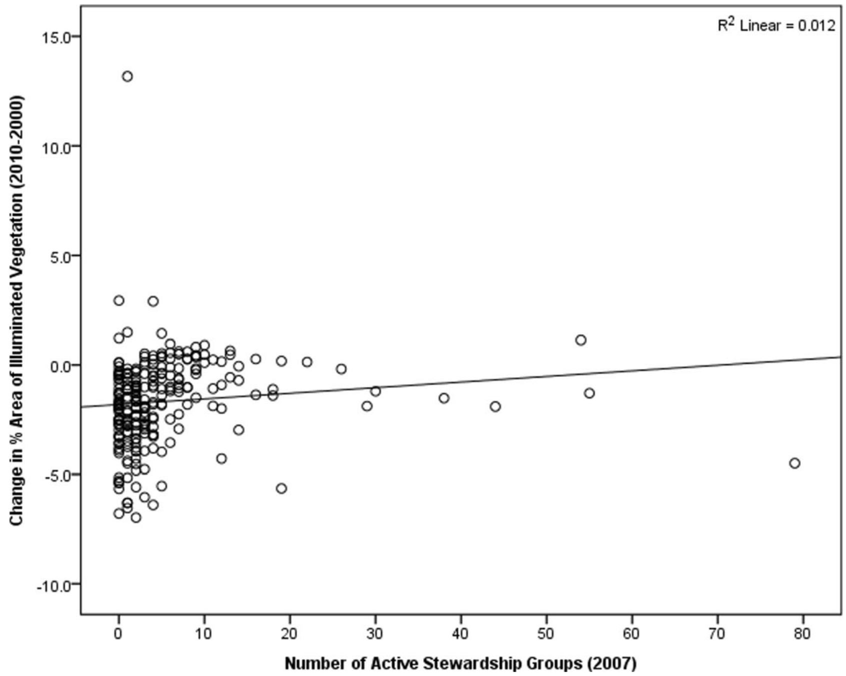


Fig. 3 The relationship between stewardship groups and the amount of vegetation change between 2000 and 2010 at the neighborhood scale is not strongly linear, and most neighborhoods do not exhibit large changes

provides qualitative information about civic and public stewardship activity in neighborhoods that fall into the different categories of building footprint and vegetation change. We examined neighborhood outliers from three quadrants that illustrate unusually large changes in vegetation and building footprint (see Fig. 3). Because there were no outliers exhibiting both an increase in vegetation abundance and building footprint, quadrant I was not explored qualitatively.

Quadrant II: increasing vegetation and loss of building footprint

Actions of stewards and park managers help to explain the pattern of vegetation and building footprint changes in quadrant II. We examine two of the outlier neighborhoods in turn: “Brooklyn Heights-Cobble [Hill]” in Brooklyn and “Westside Waterfront” in Manhattan. Brooklyn Bridge Park in the Brooklyn Heights neighborhood is an extreme case of increasing vegetation and loss of building footprint. An adaptive reuse of historic shipping piers abandoned since 1984, along the Brooklyn waterfront, Brooklyn Bridge Park will eventually total 85 acres of recreational space. This plan was developed through discussions between the city and numerous community groups, leading to a design comprised of a minimum of 80 % open space and 20 % revenue generating facilities (hotels, housing, concession) to financially sustain the park. Over the course of the 2000s, acres of impervious surface were converted to parkland, including tree canopy, shrubs, and lawn. Ground was broken in 2008, construction of the park began in January of 2009, and the first 6 acres of the park opened at Pier 1 in March of 2010. Additional acres of parkland were added in summer 2010: 3.5 acres were added at Pier 1 and 1.4 acres were added at Pier 2. While the park includes future plans for new building development, no new buildings besides small Parks Department facility buildings were constructed in the 2000s (Brooklyn Bridge 2012).

The STEW-MAP database contains one group operating in Brooklyn Bridge Park. The Brooklyn Greenway Initiative is a nonprofit charged with planning and coordinating the development of the 14-mile pedestrian and bicycle Brooklyn Waterfront Greenway connecting waterfront neighborhoods and open spaces. The Greenway was incorporated into the design of Brooklyn Bridge Park, and the park construction in 2009 converted industrial waterfront including abandoned piers, parking lots, and underutilized buildings into public open space and parkland. As part of a coalition of government and community groups, Brooklyn Greenway Initiative advocated for the creation of Brooklyn Bridge Park, along with the rest of the Brooklyn Waterfront Greenway.

Similarly, the mission of the Hudson River Park Trust in the Westside Waterfront neighborhood of Manhattan is to design, construct, manage, and operate the 550-acre Hudson River Park. According to the Hudson River Park Trust website (2012), much of the park construction occurred during our study period:

> Construction in Greenwich Village, the first section completed, began in 1999 on the upland and in 2000 on the piers. Greenwich Village was followed by Clinton Cove in 2005 and then Piers 66 and 84 in 2006.

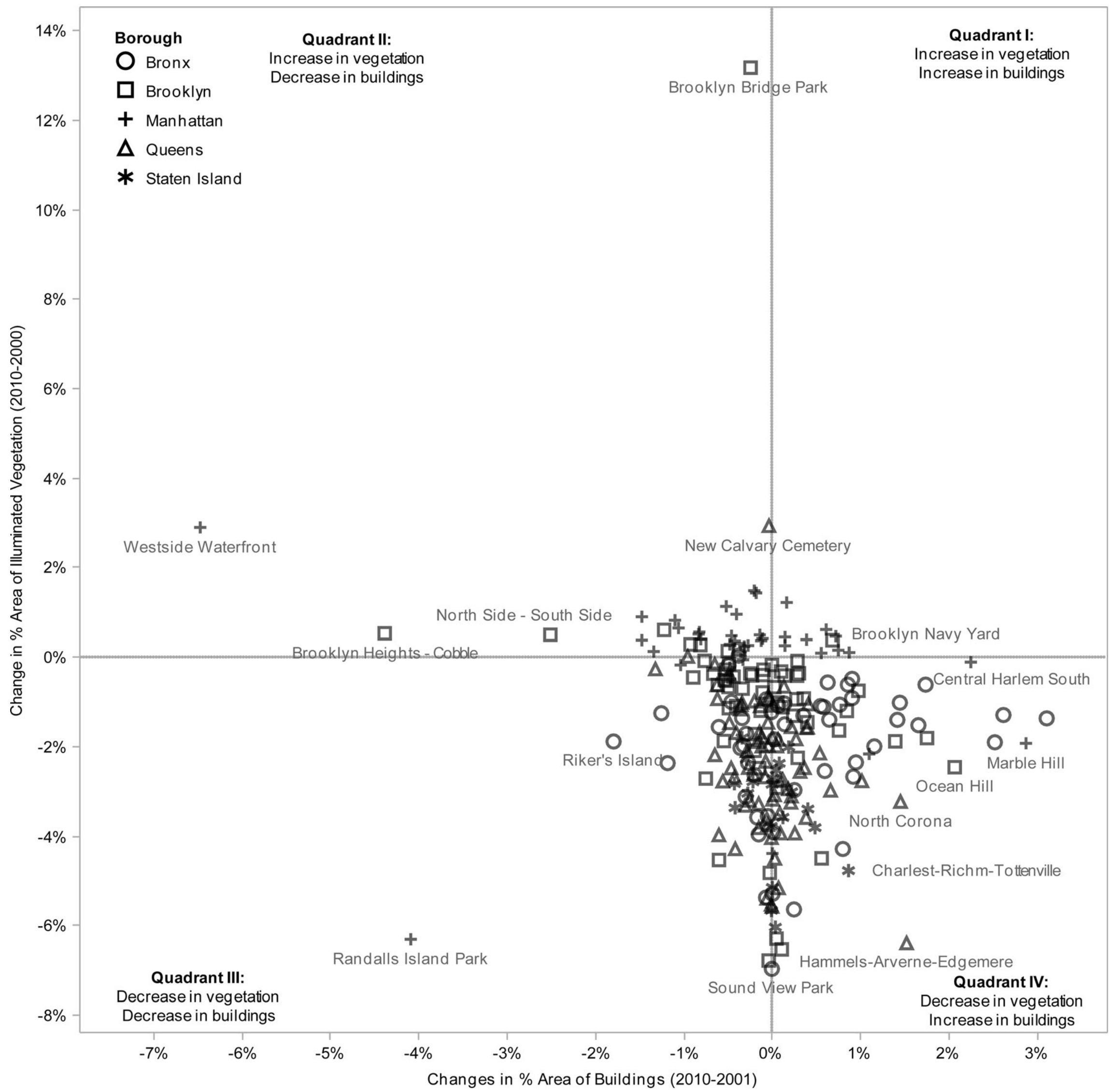


Fig. 4 Vegetation change and building footprint change along the y- and x-axes, respectively, reveal trends in development and greening among 243 New York City neighborhoods

> During this period, the Trust also completed the upland area from W. 26th St. to W. 29th Street plus the Courtyard Ball fields in Pier 40 and the Chelsea Waterside Playground. In 2010, we opened four more piers and major new upland sections in Chelsea and Tribeca. Since 1999, Hudson River Park has channeled over $350 million in public funding into rebuilding the piers, bulkheads, and land areas that comprise the Park, such that at the close of 2011, the Park was 70 percent complete. (Hudson River Park 2012).

In addition, Friends of Hudson River Park supports those efforts by advocating for parkland, funding, and constituents. Over the course of the 2000s, park construction has continued to add vegetation to the previously industrial landscape. Other groups in the Westside Waterfront neighborhood (see bottom of Fig. 5), including a neighborhood street tree stewardship group and an architectural preservation society, may further contribute to vegetation increase and maintenance.

Quadrant III: decreasing vegetation and loss in building footprint

Randall's Island Park is an example of an area in quadrant III—the park lost both vegetation and building area, a seemingly counterintuitive combination. The city-owned park containing an 8-acre salt marsh, a variety of gardens and landscaped areas, and a plethora of sports facilities is stewarded by a civic group called the Randall's Island Sports Foundation (now called the Randall's Island Park Alliance), which was established to help the City of New York restore the park. Between 2000 and 2010, the group advocated for the creation of over 60 athletic playing fields, replacing both vacant buildings and overgrown vacant lots. Construction of the fields began in 2007 and they are mostly constructed out of artificial turf, which is clearly distinguished from vegetation by the spectral mixture analysis of Landsat. Indeed, the Department of Parks & Recreation instituted a policy shift citywide toward installing more artificial turf fields after PlaNYC set a goal of converting at least two dozen asphalt playing areas to artificial turf. As of 2007, there were 36 synthetic turf fields citywide, 12 of which are located on Randall's Island, Fig. 5 shows the types of changes that occurred (The City of New York 2007: 36).

Quadrant IV: vegetation decrease and gain in building footprint

Neighborhoods in quadrant IV experienced losses in vegetation accompanied by increases in building area: the classic development pattern. Hammels-Arverne-Edgemere, three adjacent neighborhoods on the barrier island community of the Rockaways in Queens particularly illustrate this trend in land cover change and contain several environmental stewardship groups advocating for the use and preservation of local green space. Groups in Hammels-Arverne-Edgemere include stewardship groups such as the American Littoral Society and the Norton Basin Edgemere Stewardship Group, both of whose missions include the preservation of wetlands and other natural areas in and around Jamaica Bay. Specifically, the mission of the Norton Basin Edgemere Stewardship Group "to halt the further destruction of the wetland… by encroaching development" reveals that construction in this area is indeed converting green space to buildings and civic stewardship groups are working to respond to those changes. This Group in particular has been in existence since 2002 and works on both public and vacant lands including waterfront, beaches, shoreline, and greenways.

The American Littoral Society's Northeast chapter was founded in 1980, focusing on the coastal areas of New York City, serving fishermen, beach walkers, birders, and the general public. Beginning in the early 1980s, the Littoral Society became involved in coastal cleanup efforts around Jamaica Bay and participated in the Jamaica Bay Taskforce with other likeminded private, public, and civic groups. This

Fig. 5 Landscape changes from 1995 to 2010 on Randal's Island can be seen with high-resolution ortho imagery on top in panels **a** and **b**. In panels **c** and **d,** changes to a section of the Westside Water front become clear as well

involvement with the bay was further formalized in 2002 by appointing an officer to the role of "Jamaica Bay Guardian" with funding from the New York State Department of Environmental Conservation to focus on restoration, education, and advocacy in and around the bay, particularly in response to the loss of salt marshes in the bay. Specific to contesting development and preserving open space, an organizational representative of the Littoral Society gave this account:

> [Trust for Public Lands] went out and they surveyed all the lands around the bay and then we've prioritized the best natural areas that we could hopefully try to protect and then started working to get them protected. And it worked very well, a lot of all the lands in the southeast section of the Bay [have been protected]. We have Dubos Point was expected to be a big housing development. It's now a city park wetland preserve…And then several other little, wetland preserves. I guess my greatest involvement at that time was there was one property, a beautiful peninsula over there that was scheduled to be a truck body customizing plant. And that was the Economic Development Corporation, the city wanted to promote development out there. The local community board, jobs, jobs, jobs, and we kept saying, "well, jobs are plastic. You don't put them on the edge of the bay. And you know we only have remnant areas left around the bay. So let's…let's try to protect what's left." And we fought for about 2 years until finally the developer himself left, you know, he said "forget about this". And then it was turned over to…the DEP Commissioner at that time…. And then it was turned over finally to City Parks under the Henry Stern Administration. And Henry Stern was very much interested in picking up these wild lands as part of the Parks Department properties. [At the dedication] he said, "I claim this land as part of New York City's Emerald Empire."

This quotation reveals the complex network of civic, public, and private actors interacting in the preservation of open space and wetland areas around Jamaica Bay from the early 1980s to the present.

Other groups in the Rockaways are involved in environmental education and advocacy. These stewardship groups are not specifically involved in creating new natural areas, but in preserving existing vegetation. Youth Can is "a youth-run organization that uses technology to inspire, connect, and educate people worldwide about environmental issues" while the Margaret Community Corporation's mission includes "neighborhood preservation." These groups reveal that the relationship between civic stewardship and re-greening is complex and not necessarily linear. Stewardship actions can involve advocacy, education, and awareness-raising that take years to manifest in "on-the-ground" changes in the landscape.

Discussion

Our analysis of spatio-temporal vegetation change in New York City and its relationship to environmental stewardship reveals that stewardship groups may have a positive impact on vegetation change over time at the neighborhood level. While most neighborhoods experienced a small decrease in vegetation between 2000 and 2010, those that did experience an increase in vegetation tended to have more stewardship organizations present. This finding alone does not prove causation; the qualitative interview data above are intended to triangulate and contextualize these findings. When change in building footprint was considered in our analysis, we found that neighborhoods whose building footprint increased, lost vegetation when compared to those that saw a decrease in buildings. In sum: buildings may displace vegetation, which is not surprising given the densely built environment of New York City. This finding does not hold true for the borough of Manhattan, which is the only borough with an overall positive vegetation trajectory. Manhattan is the most urbanized and has the most densely built environment of all five boroughs. Given the larger amounts of vacant and therefore developable space in the other four boroughs, real estate pressure is more likely to be a driver of land cover change in those areas than in Manhattan. Additionally, we found that changes in building footprint interact with changes in vegetation and the number of stewardship groups. Greening neighborhoods have the same amount of active civic environmental groups regardless of whether buildings were lost or gained. However, among neighborhoods that lost vegetation, those that also gained building footprint have more stewards than those that lost building footprint in addition to vegetation. To explain this difference, we propose that traditional development pressures—the loss of vegetation at the expense of new buildings—may be sparking stewardship activity in these neighborhoods. These changing land use patterns may motivate grassroots environmental stewardship in addition to more traditional conservation and preservation efforts. Although more research is needed to examine the processes, mechanisms, and drivers behind this pattern, this finding is an important contribution to the study of greening in urban ecosystems.

The qualitative data presented here show how stewardship emerges locally and varies with neighborhood conditions. Intensive, process-focused data complements and reinforces the extensive, quantitative data used to detect spatial patterns in stewardship turf and landscape change (Grove et al. 2013). The efforts of civic and public actors have created new parks on the Brooklyn and Manhattan waterfronts. Public managers have transformed existing parks in response to local needs and demands for recreation, including through the creation of artificial turf fields on Randall's Island. Civic advocates contest the development of their neighborhoods and work to preserve Jamaica Bay's wetlands and surrounding ecosystems. These multifaceted interactions with the built and vegetative environments create a varied and patchy urban landscape, perhaps best described as a shifting mosaic (Grove et al. 2005). In this shifting mosaic, we suspect that urban stewardship actions may play a critical role in mediating uses and shaping certain aspects of land use development in New York City neighborhood areas.

There are several limits to this analysis. Spectral Mixture Analysis applied to Landsat detects the presence and abundance of illuminated vegetation at spatial scales finer than the 30 m resolution of the source imagery. Vegetation below the canopy or in deep shadows such as those found between tall buildings was not detected. Small changes may be attributable to partial canopy loss, removal of individual trees, or reduced vegetation vigor from water stress at the time the images were acquired. Most of the large percent changes are associated with spatially localized events like changes in building cover and re-greening efforts. Since we aggregate our data into polygons representing neighborhoods, our data are susceptible to the modifiable areal unit problem (MAUP), which occurs when analytical results may be attributable to the scale, configuration of the spatial partitioning, and/or an actual underlying phenomena of interest (Openshaw 1984). Here, using percentages of vegetation somewhat diminishes the MAUP.

Conclusion

In our study, we made use of the neighborhood as a politically and socially relevant unit of analysis for New York City. Multidisciplinary synthesis at this scale allows for a novel exploration of the relationship between environmental stewardship and vegetation dynamics in New York City from the year 2000 to 2010. We used satellite-derived vegetation estimates and GIS data representing building footprints to help identify patterns in the physical environment. Social survey response data and interviews with key informants on the history and role of stewardship organizations in New York City across the study period provide information on the processes and mechanisms that help explain the spatio-temporal vegetation trends. Our aim was to understand the interactions between social and biophysical infrastructure in New York City and how these interactions shape urban ecosystem dynamics.

Our application of Grove and others' (2013) extensive-intensive data framework facilitates a mixed-methods analysis highlighting the importance of stewardship generally, but does not provide a complete picture of all potential drivers of vegetation change in New York City neighborhoods. Instead, we have (a) identified that most neighborhoods lost vegetation from year 2000 to 2010, (b) shown that greening neighborhoods tended to have more stewardship organizations than chance alone can explain, when controlling for the confounding role of changes in the built environment, and (c) using three case studies, described and explained how civic stewardship organizations and public land management influence the spatio-temporal distribution of vegetation in New York City. Given that stewardship does not act in isolation of other drivers of vegetation change, its relative importance to other variables could be explored; these might include changes in zoning and land use, as well as the spatial distribution of sociodemographic variables. These potential factors could be explored in combination while they are acting at varying intensities and at different spatial and temporal scales. Such analyses may reveal the importance of local community action on urban ecosystem structure.

While this study demonstrates the association between the number of active environmental stewardship groups and changes in neighborhood-scale vegetation, the lack of a clear linear relationship between vegetation change and civic stewardship indicates the complexity of urban ecosystems at the neighborhood scale. The relationship between socioeconomic conditions and vegetation cover warrants further investigation, especially in combination with other biophysical and built environment variables across both space and time. As the demand for liveable and sustainable cities continues to grow alongside the population of urban areas, this line of inquiry will provide a greater understanding of how to manage complex urban systems in the future.

Acknowledgments The authors acknowledge support from the National Science Foundation Urban Long Term Research Area Exploratory (ULTRA-Ex) grant DEB-0948451, the US Forest Service Northern Research Station, the Libby Fund Enhancement Award from Clark University, and the Carpenter-Sperry Award. We also thank Walter Rosenbaum, Jessie Braden (Pratt Institute for Community Development), James Connolly (Northeastern University), and our anonymous reviewers for helpful input.

References

Adams JB, Smith MO, Johnson PE (1986) Spectral mixture modeling: a new analysis of rock and soil types at the Viking lander 1 site. J Geophys Res 91:8089–8122

Anderson J, Hardy, E, Roach, J, Witmer, R (1976) Land use and land cover classification systems for use with remote sensor data. USGS prof paper 964

Beattie J, Kollin C, Moll G (2000) Trees tackle clean water regs. Am For 106:18–19

Beckett K, Freer-Smith P, Taylor G (2000) Effective tree species for local air quality management. J Arboric Urban For 26:12–19

Brooklyn Bridge Park, 2012. Brooklyn Bridge Park. Retrieved Nov 19th, 2012 from http://www.brooklynbridgepark.org/the-park

Cadenasso M, Pickett STA, Schwarz K (2007) Spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification. Front Ecol and the Environ 5:80–88

Campbell LK (2014) Constructing New York City's urban forest: the politics and governance of the Million Trees NYC campaign. In Sandberg LA, Bardekjian A, Butt S, (eds) Urban Forests, Trees, and Green Space: A Political Ecology Perspective. Earthscan/Routledge.

Connolly JJ, Svendsen ES, Fisher DR, Campbell LK (2013) Organizing urban ecosystem services through environmental stewardship governance in New York City. Landsc Urban Plan 109:76–84

Dwyer J, McPherson E, Schroeder H, Rowntree R (1992) Assessing the benefits and costs of the urban forest. Arboric Urban For 18:227–234

ESRI, 2009, ArcMap 9.3.1 Redlands, California: ESRI.

Fernandez-Juricic E (2000) Avifaunal use of wooded streets in an urban landscape. Conserv Biol 14:513–521

Fisher D, Campbell LK, Svendsen ES (2012) The organizational structure of urban environmental stewardship. Env Polit 21:26–48

Grove JM, Burch WR, Pickett STA (2005) Social mosaics and urban community forestry in Baltimore, Maryland introduction: rationale for urban community forestry continuities from rural to urban community forestry. In: Lee RG, Field DR (eds) Communities and forests: where people meet the land. Oregon State University Press, Corvalis, pp 248–273

Grove JM, Pickett STA, Whitmer AC, and Cadenasso ML (2013) Building an Urban LTSER: the case of the Baltimore Ecosystem Study and the D.C./B.C. ULTRA-Ex Project. In Singh SJ, Haberl H, Chertow M, Mirtl M, Schmid M (Eds.) Dordrecht: Springer Netherlands. doi:10.1007/978-94-007-1177-8

Hager MA, WilsonS PTH, Rooney PM (2003) Response rates for mail surveys of nonprofit organizations: a review and empirical test. Nonprofit Volunt Sect Q 32(2):252–267

Hartig T, Mang M, Evans G (1991) Restorative effects of natural environment. Env Behavior 23:3–26

Hudson River Park Trust (2012) Planning and construction. Retrieved November 19th, 2012 from http://www.hudsonriverpark.org/vision-and-progress/planning-and-construction

IBM (2009) PASW statistics 18.0.0. IBM (SPSS), Chicago

Kovacs KF, Haight RG, Jung S, Locke DH, O'Neil-Dunne J (2013) The marginal cost of carbon abatement from planting street trees in New York City. Ecological Econ 95:1–10. doi:10.1016/j.ecolecon.2013.08.012

Kuo F, Sullivan W (2001) Aggression and violence in the inner city: effects of environment via mental fatigue. Env Behavior 33:543–571

MacFaden SW, O'Neil-Dunne JPM, Royar AR, Lu JWT, Rundle AG (2012) High-resolution tree canopy mapping for New York City using LiDAR and object-based image analysis. Appl Rem Sens 6:1–23

McPherson G, Nowak DJ, Rowntree R (1994) Chicago's urban forest ecosystem: results of the Chicago urban forest climate project. General Technical Report NE-186. USDA Forest Service Northeastern Forest Experimental Research Station, Radnor, Pennsylvania

Nowak DJ (2002) The effects of urban trees on air quality. Retrieved January 26th, 2011 from http://nrs.fs.fed.us/units/urban/local-resources/downloads/Tree_Air_Qual.pdf

Nowak DJ, Crane D (2002) Carbon storage and sequestration by urban trees in the USA. Environ Pollut 116:381–389

Nowak DJ, Greenfield EJ (2012) Tree and impervious cover change in U.S. cities. Urban For Urban Green 11(1):21–30. doi:10.1016/j.ufug.2011.11.005

Nowak DJ, McHale P, Ibarra M, Crane D, Stevens J, Luley C (1998) Modeling the effects of urban vegetation on air pollution. In: Gryning S, Chaumerliac N (eds) Air pollution modeling and its application XII. Plenum Press, New York, pp 399–407

Nowak DJ, Hoehn R, Crane D, Stevens J, Walton J (2007) Assessing urban forest effects and values: New York City's urban forest. Retrieved January 26th, 2011 from http://www.nrs.fs.fed.us/pubs/rb/rb_nrs009.pdf

O'Neil-Dunne JPM (2012) A Report on the City of New York's existing and possible tree canopy. http://www.fs.fed.us/nrs/utc/reports/UTC_NYC_Report_2010.pdf Accessed July 15, 2013

Openshaw S (1984) The modifiable areal unit problem. Concepts and Tech in Mod Geogr 38:1–41

Romolini M, Grove JM, Locke DH (2013) Assessing and comparing relationships between urban environmental stewardship networks and land cover in Baltimore and Seattle. Landsc Urban Plan 120:190–207. doi:10.1016/j.landurbplan.2013.08.008

Rosenfeld A, Akbari H, Romm J, Pomerantz M (1998) Cool communities: strategies for heat island mitigation and smog reduction. Energ Build 28:51–62

Rudd H, Vala J, Schaefer V (2002) Importance of backyard habitat in a comprehensive biodiversity conservation strategy: a connectivity analysis of urban green spaces. Restor Ecol 10:368–375

Scott J (2000) Social network analysis: a handbook (2nd ed.). Sage Publications, London

Small C (2001) Estimation of urban vegetation abundance by spectral mixture analysis. Intl J Remote Sens 21:1305–1334

Small C (2004) The Landsat ETM+spectral mixing space. Remote Sens Environ 93:1–17

Small C, Lu JTW (2006) Estimation and vicarious validation of urban vegetation abundance by spectral mixture analysis. Remote Sens Environ 100:441–456

Svendsen ES, Campbell LK (2008) Urban ecological stewardship: understanding the structure, function and management. Cities and the Environ 1:1–31

The City of New York, Mayor Michael R. Bloomberg (2007) PlaNYC: a greener, greater New York. Retrived November 19th, 2012 from http://www.nyc.gov/html/planyc2030/html/theplan/the-plan.shtml

Tooke T, Coops N, Goodwin N, Voogt J (2009) Extracting urban vegetation characteristics using spectral mixture analysis and decision tree classifications. Remote Sens Environ 113:398–407

Van de Voorde T, Vlaeminck J, Canters F (2008) Comparing different approaches for mapping urban vegetation cover from Landsat ETM+data: a case study on Brussels. Sensors 8:3880–3902