Title

Urban Ecosystem Services in New York City: A Social-Ecological Multi-Criteria Approach

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Urban ecosystem services, multi-criteria analysis, stacking, social-ecological systems, resilience, urban planning, sustainability, New York City

Abstract

As urbanization expands, there is a need for city planners and policymakers to consider how ecological resources can be strategically developed and managed sustainability to meet the needs of urban populations. Local and regional ecosystems provide important functions that benefit urban residents, including stormwater retention, air pollution removal and heat mitigation (Bolund et al., 1999). The ecosystem services approach provides a useful framework for assessing the status quo, setting goals, identifying benchmarks and prioritizing approaches to enhance ecological functions in ways that better serve urban communities. In order to facilitate urban sustainability and resilience planning, practitioners and policymakers require tools for comprehensively evaluating urban ecosystem services in order to manage ecosystems for maximal ecosystem functioning and to evaluate how local and regional trends and plans may affect the provisioning of local and regional critical ecosystem services. We develop an urban ecosystem service assessment methodology that can be used to identify current conditions and priority areas for ecological planning which considers social-ecological conditions and relationships, as well as spatial patterns of these conditions and relationships across the urban landscape. The social-ecological analysis presented here focuses on vacant lots in New York

City, understudied areas of the city, which by virtue of being undeveloped, hold potential for ecosystem services planning. Results suggest that a combined social-ecological approach to ecosystem services assessment yields new tools for assessing, monitoring, and stacking ecosystem services. We find that vacant lots with high ecological value are concentrated in Staten Island and the North Bronx, and that distinct clusters of vacant lots with overlapping low ecological value and high social need (such as low income and low concentration of green space) are primarily concentrated in three areas of the city – Harlem, the Bronx and Brooklyn.

1. Introduction

The world is increasingly urban, interconnected and changing (Seto et al., 2011). Over the last few decades there has been increasing recognition that human population expansion and development, especially in cities, is reshaping the ecology of the entire planet (Alberti et al., 2003; Folke et al., 2003; Rockström et al., 2009). Urban regions create significant disproportionate direct and indirect environmental impacts at the local, regional and global scale that affect local and global sustainability (Grimm et al., 2008; Grimm et al., 2000; Seto et al., 2012). Given global urbanization trends compounded by the effects of climate change and other global environmental pressures (IPCC, 2011; Rockström et al., 2009), the primary dynamic that must be understood for increasing urban sustainability and resilience is the social-ecological relationships between humans and the urban ecosystems in which the majority of people live (Folke, 2006; Steward et al., 2009). To improve urban sustainability while also increasing resilience city planners and policymakers will have to consider how ecological resources can be strategically developed and best managed to meet the needs of urban populations.

Local and regional urban ecosystems provide important functions to urban residents, habitat for biodiversity, primary productivity, stormwater retention, air pollution removal and heat mitigation (Bolund et al., 1999). The ecosystem services (ES) approach provides a useful framework for assessing the status quo, setting goals, and identifying benchmarks that facilitate long-term monitoring and prioritizing approaches to enhance ecological functions in ways that serve urban communities (Daily et al., 2009; Niemelä et al., 2010; Sukhdev et al., 2010). Practitioners and policymakers require new policy-support tools for comprehensively evaluating tradeoffs and synergies among multiple urban ecosystem services (UES) in order to maximize ecosystem functioning and to evaluate how local and regional change and urban planning may alter the provisioning of critical UES over time (Larsen et al., 2008). In particular, spatially-explicit tools are needed for decision-makers to consider the site suitability of crucial ES (Chan, et al., 2006; de Groot et al., 2010; Seto et al., 2012). Here, we develop an ES assessment methodology that can be used to identify current conditions and priority areas for ecological planning which considers social-ecological conditions and relationships, as well as spatial patterns of these conditions and relationships across the urban landscape. We present a social-ecological analysis that focuses on vacant lots in New York City (NYC), understudied areas of the city, which by virtue of being undeveloped, hold potential for ES planning.

2. Urban Ecosystem Services

2.1 Urban Social-Ecological Systems

Urban areas are made up of complex combinations of heterogeneous social-ecological patches (Cadenasso et al., 2007). The Human Ecosystem Framework (Machlis et al., 1997; Pickett et al., 2001) has provided a useful theoretical context to integrate natural and institutional resources, social structure, ecological processes, and spatial patterns across the urban landscape (Pickett et al. 2010). The spatial heterogeneity of urban systems has been well noted (Jacobs, 1961; Pickett et al., 2007), however, the interaction of various kinds of heterogeneity in urban systems is a major open question (Pickett et al., 2008). Despite the analytical challenges to working in heterogeneous urban systems, efforts to understand reciprocal interactions across social-ecological systems have identified strong relationships between social and vegetation characteristics in urban areas. Lifestyle behavior, housing age, family size, marriage rates and other demographic characteristics of neighborhood residents have been linked to vegetation cover and biodiversity in urban areas (J. Grove et al., 2006).

In coupled social-ecological systems, mutual dependence exists between social communities and ecological processes with interactions and feedbacks affecting each other over time (Folke, 2006; Holling, 2001; Peterson, 2000). As natural resources become limited, there is a growing need to identify whether and how resilience of ecological systems is related to resilience of social institutions and vice-versa. In this context, social-ecological resilience can be a useful conceptual framework for sustainability planning (Wilkinson, 2011). Adger suggests that "[s]ocial resilience has economic, spatial and social dimensions…" and "is related to the social capital of communities (2000 pp. 349)." Ways in which social and ecological systems are linked have been examined in a number of communities that depend on natural resources for economic productivity (Agrawal, 2001; Olsson, et al., 2004). For example, neighborhoods in New York City have differential access to social capital, and therefore, potentially differential capacities to exert influence over the urban landscape. While our study does not hypothesize which specific dynamics link social communities to ecological processes in NYC neighborhoods, it does identify patterns in the configuration of ES and socio-economic indicators across the NYC urban landscape. Identifying these patterns can enable researchers to develop more refined hypotheses about the mechanisms that link social communities to ecological processes.

2.2 Ecosystem Services

Since the Millennium Ecosystem Assessment (MA) (2005), ES have been widely conceptualized as connecting natural resources and the human economy (TEEB, 2011). Urban forests and other green spaces in cities especially have been widely documented for providing a variety of important UES (Akbari, 2002; Grove et al., 2005; McPhearson, 2011; McPhearson et al., in press; Nowak et al., 2002; Troy et al., 2007). In the MA framework, stocks of natural resources and a host of regulating cycles and support mechanisms underlie the social and economic capacity to support human development and well-being (Felix et al., 2011). As the human population expands, larger quantities of matter and energy are appropriated from the biosphere, which has a constant and finite flow rate of both (Røpke, 2005). Consequently, as consumption of natural resources moves closer to the planetary boundaries of natural resources regeneration rates (Rockström et al., 2009), the ability of the natural environment to support human development and well-being is eroded. In a world operating near or beyond these boundaries, there is growing need for the assessment, evaluation, and monitoring of the capacity of the natural environment to provide services and support human well-being (MA, 2005).

The concept of ES requires the concurrent analysis of the biophysical and ecological foundation of ecosystems and the ways human beings use, benefit, and value these ecosystems (R S De Groot et al., 2010). Thus, addressing ES inherently requires a social-ecological perspective (Folke, 2006) and multidisciplinary tools for analysis (Seto et al., 2012). Ecosystem services can be quantified either as the biophysical units of the service provided or the societal value of the service (most often monetary value) (Felix et al., 2011) and the choice of valuation method should be strongly informed by the research goals. The primary valuation methods can be grouped into preference based approaches and biophysical approaches (Sukhdev et al., 2010).

Preference based approaches include all monetary and non-monetary societal value setting and biophysical approaches include assessments that are grounded in processes, flows and structures of the ecosystem. Biophysical approaches to ES valuation most often remain at the level of flow analysis (e.g. input-output, material flow) or as aggregated totals of production-consumption value collapsed into one variable (e.g. global acres and carrying capacity in ecological footprint analyses; (Rees & Wackernagel, 1996)). Though such biophysical analyses provide needed insight into the appropriation of natural capital by the human economy, they offer limited capacity for decision making and planning for ecosystem sustainability.

Much of the economic valuation of ES remain limited to those services which have use value and thus can be valued (directly or indirectly) as goods in neoliberal economic markets. Non-use services and other social and cultural aspects of ES are less well studied although work on their valuation has been progressing (Barthel et al., 2010; Calvet-Mir et al., 2012; Chan et al., 2011). At a more theoretical level, critics of economic valuation of ES argue that a robust science behind the complex linkages between biological diversity, non-linear system dynamics in ecological systems and the human systems they support, is yet to be developed (Dempsey et al., 2012), thus attempts to quantify the economic value of such systems may be overly simplistic and potentially erroneous. There can also be ambiguity in the way different researchers distinguish between services, functions, and benefits and therefore valuation discrepancies arise. Nonetheless, the integrity of ecosystems and their functions provide the basis for the provision of services and should not be disregarded (Felix et al., 2011). Useful classification and evaluation schemes of ES need to take into account the complex nature of ecological systems, including its non-linear nature, the joint production of ES, the multiple spatial-temporal characteristics, as well as the variety of beneficiaries and decision contexts in which ES are evaluated (Fisher et al., 2009). This evaluation should include investigating the equitable distribution of resources and social-cultural need for ES. Developing methods that are able to account for these multiple perspectives is one of the pervasive challenges in making ecosystem approaches to urban planning operational at the policy and decision making level.

2.3 Stacking Ecosystem Services

Concurrent assessment of multiple ES, often referred to as “stacking” or “bundling,” has been a contentious issue in the development of ecosystem valuation methods (Cooleyr et al., 2012). Nonetheless, the importance of considering multiple ES for the purpose of decision making in the context of green infrastructure planning and resource conservation management has been increasingly acknowledged (Weber et al., 2009; Felix et al., 2011; Hepcan et al., 2011; Koniak et al., 2010).

Research has only recently begun to provide tools and methods for ES stacking. Buckland et al. (2005) offered a composite indicator analysis for monitoring change in biodiversity and more recently Naidoo et al. (2008) stacked four ES based on their biophysical units and spatial distribution and correlated average service provisions with a measure of biodiversity. They suggest that using such a methodology is effective in identifying areas of enhanced opportunity (win-win areas) or need. It is also important to understand tradeoffs and synergies between different ES. For example, Nelson et al. (2008) modeled ES tradeoffs and synergies showing that optimizing for one service does not necessarily results in improvement in the other and those policy scenarios that support one specific service may have limited capacity to improve other ES. An important conclusion from this study and others is the need for methodological and empirical capacity to address multiple ES in policy analyses using a systems approach to investigating social and ecological processes (Felix et al., 2011). Effective decision making in setting conservation priorities requires local methodologies that can map multiple ES and biodiversity indices at multiple scales from global to local (Naidoo et al., 2008b) and effectively communicate and visualize policy and decision options and possibilities (Tallis et al., 2009).

Given global urbanization and environmental change trends, we expect there to be intense pressure on urban ecosystems to provide critical services suggesting that it is paramount to quickly develop locally relevant evaluation methods for stacking ES (Bolund et al., 1999; Dobbs et al., 2006; Lundy et al., 2011). Urban ecosystems stressors included air pollution, water contamination, limited water supply, noise, and regular human disturbance (Mortberg et al., 2000). In New York City, the effects of climate change including sea level rise, changing heat and precipitation patterns, and storm frequency and intensity are predicted to place increased pressure on local urban ecosystems to provide critical UES (New York City Panel on Climate Change, 2009). Only by analyzing the range of services provided by different urban ecosystems, how they change over time, and the factors that strengthen or limit their performance, will local and regional policymakers understand how to harness ES to achieve short-term public policy objectives (e.g., stormwater management) while enhancing the long-term resilience and adaptive capacity of our communities (and the human and non-human members within them) to changing urban environments.

3. Conceptual Framework and Methods

Our study involves linking social, biological, and infrastructural heterogeneity in a spatially explicit conceptual framework to investigate a broad set of social-ecological indicators of UES in NYC. We examined vacant lots, some of the most heterogeneous urban spaces (Pennsylvania Horticulture Society, 1995) in New York City from a combined social-ecological approach in order to integrate social and ecological components of the NYC system across space and disciplines to examine the reciprocal feedbacks between social-ecological system patterns and UES. Vacant lots are underdeveloped and underused lands in cities (Pennsylvania Horticulture Society, 1995; Tidball et al., 2010) that may present an opportunity to enhance concurrently ecological and social services in associated neighborhoods. New York City has 29,782 land parcels identified as vacant in the city's MapPluto tax lot database (NYC Department of City Planning, 2011), including both publically and privately owned vacant land. To estimate the potential social-ecological services of vacant land we analyzed the landcover and land uses of a sample of 1502 vacant lots (5%) in the all give boroughs of NYC (Manhattan, Bronx, Queens, Brooklyn, and Staten Island). This study approaches vacant lots as a part of the urban fabric with complex social-ecological relationships. Although vacant lots are often discussed as an adverse influence on neighborhoods (Kremer et al., unpublished) we suggest that vacant lots can be viewed as providing important sources of social-ecological value depending on their social uses and ecological functioning. Here, we assess the combined social–ecological value of NYC vacant lots.

3.1. Social-Ecological Multi-Criteria UES Assessment

Our social-ecological approach to assessing urban indicators for ES involved a multi-step methodology that included data collection from existing sources regarding green infrastructure and socio-economic indicators in the city, and a stratified random sample and analysis of the landcover and land use in 1,500 vacant lots across the five boroughs of New York City. We also calculated indicators of the relative quality of multiple ES using multiple criteria of the sampled vacant lots and socioeconomic indicators of the neighborhoods surrounding them, and stacked ES and socioeconomic indicators through a scaling and weighting process for the purpose of comparing social-ecological values across vacant lots.

Vacant lots in NYC were identified through a spatially referenced city tax lot database (NYC Department of City Planning, 2011). A stratified 5% random sample of lots from each borough (using SAS® 9.2) was selected based on borough and lot area. Lots were then grouped into size categories using the Jenks optimization method (Longley et al., 2011). The Jenks method groups lots into area by maximizing between-group differences while minimizing within-group differences, allowing us to identify the natural groupings of lot area. We then compared the median and mean lot area for each group of the sample with median and mean lot area for each group of the population. Finding that large lots were under-represented, we added a small group of large lots to each borough sample in order to adequately represent lot area. Table 1 shows the number of vacant lots in the population, the sample stratified by borough only and the sample stratified by borough and lot area, as well as the percentage of lots sampled in each borough.

Table 1: NYC Vacant Lots Sample and Population Figures

Borough	No. of lots (Total population)	Sample (5%) of Lots Stratified by Borough	Sample Stratified by Borough and Lot Area
Brooklyn	7902	395	397
Bronx	4167	208	210
Manhattan	1282	64	67
Queens	8552	428	430
Staten Island	7879	394	398
Total	29782	1489	1502

3.2. Data Collection

Vacant lot landcover and land use data were collected by visually inspecting the sampled vacant lots in Google earth. A GIS vector file was overlaid on Google Earth's digital globe and the following information extracted: building typology, percent cover of building, pavement, bare soil, coarse vegetation, fine vegetation and water. In addition, using the high resolution zoom-in and Street View functions in Google Earth, actual use was determined for each sampled lot.

To account for the heterogeneous nature of urban lots, we modified the classification High Ecological Resolution Classification for Urban Landscape and Environmental Systems (HERCULES) scheme developed by Cadenasso et al. (2007) to address the fine, heterogeneous spatial characteristics of urban landscapes by combining landcover, land use and ancillary GIS data. The HERCULES modifications we applied refined the percent landcover classes and building typologies to better characterize their representation in NYC lots. For each of the landcover classes we defined one of the following semi-quantitative percent cover classes: (0) absent; (1) present-10.99% cover; (2) 11-35.99%; (3) 36-55.99%; (4) 56-75.99%, (5) >76%. In evaluating ES based on landcover classes, we took a conservative approach, by estimating area on a range between a) the lowest value of each percent cover class (e.g., for class (2) the lowest value is 11% and b) the midpoint within the class (e.g., the midpoint for class (2) is 12.5%. These minimum and midpoint landcover percentages were then multiplied by total lot area to obtain area in each landcover class, except for lots having only one landcover class. In these cases, 100% of the lot area was assigned to a single landcover class. This approach likely underestimates landcover areas, and therefore potentially undervalues ES in the vacant lots. In these cases a 100% of the area is assigned to the landcover class.

Building typology was determined based on the following classes: (0) No building; (1) Single structures; (2) Multiple occupancy structures under 4 stories; (3) High-rises between 4–10 stories; (4) Towers greater than 10 stories; (5) Industrial building; (6) Accessory structures (pools, gazebos, decks, sheds, garages). Additionally, to provide a finer understanding of the social use of vacant lot, an ‘actual use’ category was developed to describe the variety of land uses occurring in the surveyed lots. Actual use was determined by visually assessing vacant lots in Google Earth and Google Street View and classified (for a more detailed discussion of the survey methodology see Kremer et al., unpublished).

3.3. Evaluation of Ecosystem Services

ES were evaluated based on the biophysical benefits they provide. A literature review was conducted to establish the list of ES most relevant to urban areas and applicable in the context of urban vacant lots. Relevant ES include regulating services such as carbon storage and sequestration, local climate regulation, air pollution removal and runoff mitigation. Provisioning ES included the provision of food through food production in community gardens, which can be present in vacant lots in NYC.

We used a combination of the data collected in our sample and literature review to calculate the total amount of service provided, per vacant lot, for each ecosystem service, based on the appropriate biophysical unit. Where calculating the total benefit of a specific service was not possible (e.g. runoff mitigation) an indicator is used to signify the quality or level of service provided. Place-specific literature was used to the maximal extent possible. Namely, NYC data was preferred over US data, which was preferred over international urban data. Table 2 summarizes the ES analyzed in this study, the indicators and the data and literature sources used in the analysis. Very little information about how people use vacant lots is publicly-available. Therefore, measures of cultural services provided by vacant lots are limited, although we recognize that depending on their actual use, social, cultural and health benefits are most likely occurring in many vacant lots. Moreover, we suggest that evaluating cultural, social and health benefits associated with vacant lots is essential for the assessment of the social-ecological potential value of vacant lots and can be used as a tool for planning and prioritizing the redevelopment of public and private vacant lots. Further research is necessary to address these issues in a comprehensive manner. Below are detailed descriptions of the methods used in the evaluation.

3.3.1. Carbon Sequestration

The carbon sequestration metric was evaluated on an annual basis for coarse vegetation in vacant lots, using a NYC-based estimate for trees (Nowak et al., 2002). The estimated net sequestration rate of 0.12 kgC/year/m^2 for trees in NYC is based on approximate tree conditions, sizes and estimated tree mortality. Nowak & Crane estimate that net sequestration of trees in most United States cities is 75% of gross sequestration. However, NYC has a relatively high proportion of dead trees and relatively large tree diameters, yielding a lower net estimate of only 54% of gross carbon sequestration on a per area basis. The carbon sequestration rate per square meter was multiplied by the area of coarse vegetation in the sampled vacant lots. Since we could not identify comparable estimates for grass and herbaceous vegetation in the urban literature, our evaluation of carbon sequestration excluded these landcover types.

Table 2: Ecosystem services indicators, data and literature source

Ecosystem Service	Indicator	Data	Literature Sources
Provisioning services			
Food production	Community garden (yes/no)	Sample data	-
Regulating Services			
Carbon Seq.	Coarse veg area * avg. sequestration rate (kg/m^2)	Sample data	Nowak et al. (2002 p. 385); (Akbari, 2002)
Carbon storage **Coarse veg.** **Fine veg.** **Soil**	Coarse veg area *avg. storage rate (kgC/ m^2) Fine veg area * avg. storage rate (kgC/ m^2) Soil area * carbon density/ m^2 (kgC/ m^2)	Sample data	Nowak et al. (2002); Jo et al. (1995); Pouyat et al. (2002)
Air pollution removal	Coarse veg area* pollution removal rate (g/yr) Fine veg area* pollution removal rate (g/yr)	Sample data	Nowak et al. (2002); Yang et al. (2008)
Local temp regulation	Cooling by vegetation (℃)	Sample data	Huang et al. (1987)
Runoff mitigation	Runoff coefficient (% precipitation absorbed)	Sample data, NYC soil survey	USDA (1986), NYC Soil Survey Staff (2005), Tratalos et al. (2007); Whitford et al. (2001)
Support Services			
Habitat **Habitat Avail.** **Ecological priority areas**	%green, brown and blue Situated within high priority area- community occurrences, bird conservation, TNC priority ecoregions	Sample data, NYSDEC, (2009), TNC, (n.d.)	Turner (1989) ; Whitford et al. (2001)
Connectivity	Proximity to green areas	NYC green layers	NYS GIS Clearinghouse; NYC Open Map
Shape	Compactness	Sample data	-
Size	Size of total green space	Sample data, NYC MapPluto	NYC Department of City Planning (2011)
Cultural services			
Publicly owned	Owned publicly (yes/no)	NYC MapPLUTO	NYC Department of City Planning (2011)
Recreation	Used by the public for recreation	Sample data	-

3.3.2. Carbon Storage

Carbon storage was estimated for coarse vegetation, fine vegetation and soil carbon in vacant lots. Carbon storage for coarse vegetation was evaluated based on Nowak & Crane's (2002) estimate that trees in NYC store 7.3 kgC/m^2. This is lower than the median carbon storage for trees in urban areas, which they estimate to be 9.25 kgC/m^2. The metric used to estimate carbon storage of fine vegetation was derived from a Chicago-based study that measured the carbon uptake of grass in two city blocks to be 0.18 kgC/m^2. We do not expect that carbon storage of grass on two city blocks of Chicago is equivalent to carbon storage of fine vegetation in NYC. However, given that the fine vegetation category includes shrubs and other types of vegetation, which typically have higher carbon storage values than grass, this metric can be considered quite conservative. Actual carbon storage by fine vegetation including herbaceous and shrub cover is likely much more. Moreover, Kulshreshtha et al. (2000) estimate that a Canada prairie ecosystem stores 0.19 kgC/ m^2, providing support that 0.18 kgC/m^2 is a reasonable estimate for the carbon storage of grass. The metric for soil carbon is based on Pouyat et al. (2002) estimate of C density of urban soils of 8.2 kgC/ m^2. To calculate soil area, we summed the total area of coarse vegetation, fine vegetation and bare soil. However, since we were unable to detect whether landcover under tree canopy is pervious or impervious, we excluded coarse vegetation in lots that had mostly impervious surfaces (paved landcover and buildings) from the soil carbon estimate.

3.3.3. Air Pollution Removal

Air pollutant removal by coarse and fine vegetation were estimated using metrics from an urban forest survey of trees in Brooklyn, New York, which took place in 1994 during nonprecipitation periods (Nowak et al., 2002), and a survey of pollution removal rates of vegetation on green roofs in Chicago over a one-month period (Yang et al., 2008). Both the Brooklyn and Chicago-based studies surveyed removal of SO_2, NO_2, PM_{10}, and O_3, while the Brooklyn-based study surveyed CO in addition. No comparable metrics for CO removal by fine vegetation were found in the literature. Although Yang et al. provide an estimate for the removal of O_3 by fine vegetation, this metric was not used in our evaluation. Yang et al. estimates that short grass removes 4.49 g/m^{2}yr, while the Brooklyn-based study by Nowak et al. estimates that trees remove 3.06 g/m^{2}yr (Yang et al. estimate 7.17 g/m^{2}yr O_3 removal by trees). Acknowledging this inconsistency, we used the more conservative estimate for trees, and avoided estimating O_3 removal by fine vegetation altogether. Therefore, the effect of air pollution removal by fine vegetation is conservatively undervalued in our study for both CO and O_3. Table 3 summarizes the metrics used to estimate air pollution removal rates of coarse and fine vegetation in NYC vacant lots.

Table 3: Summary of literature values used to estimate air pollution removal services of trees, shrubs and herbaceous landcover

Pollutant	**Trees**	**Shrubs**	**Vegetation**
SO_2	1.01 g/m^{2}yr (Yang et al., 2008) 1.32 g/m^{2}yr (Nowak et al., 2002)	1.13 g/m^{2}yr (Nowak et al., 2002)	Short grass: 0.65 g/m^{2}yr (Yang et al., 2008) Tall veg: 0.83 g/m^{2}yr (Yang et al., 2008)
NO_2	3.57 g/m^{2}yr (Yang et al., 2008) 2.54 g/m^{2}yr (Nowak et al., 2002)	1.92 g/m^{2}yr (Nowak et al., 2002)	Short grass: 2.33 g/m^{2}yr (Yang et al., 2008) Tall veg: 2.94 g/m^{2}yr (Yang et al., 2008)
PM_{10}	2.16 g/m^{2}yr (Yang et al., 2008) 12.5 g/m^{2}yr (Escobedo et al., 2009) 2.73 g/m^{2}yr (Nowak et al., 2002)	12.3 g/m^{2}yr (Escobedo et al., 2009) 2.12 g/m^{2}yr (Nowak et al., 2002)	Short grass: 1.12 g/m^{2}yr (Yang et al., 2008) Tall veg: 1.52 g/m^{2}yr (Yang et al., 2008)
O_3	7.17 g/m^{2}yr (Yang et al., 2008) 3.06 g/m^{2}yr (Nowak et al., 2002)	2.42 g/m^{2}yr (Nowak et al., 2002)	Short grass: 4.49 g/m^{2}yr (Yang et al., 2008) Tall veg: 5.81 g/m^{2}yr (Yang et al., 2008)
CO	.58 g/m^{2}yr (Nowak et al., 2002)	.58 g/m^{2}yr (Nowak et al., 2002)	

3.3.4. Local Temperature Regulation

The metric for local temperature regulation is the temperature reduction of the lot due to vegetation on the lot. Trees reduce local air temperature by transpiration, as they release water into the atmosphere. Cooling effects of trees can be estimated based on the ratio of latent enthalpy hours (LEH) to cooling degree days (CDD) in a city (McPherson et al., 1999). This ratio accounts for the place-specific climate characteristics that are related to the amount of vegetation required to affect temperature. NYC's LEH/CDD ratio is 1.5, which is associated with a 0.05℃ decrease in temperature per percentage increase in tree cover. To estimate the temperature reduction per lot by vegetation on the lot, the percent of the total lot covered by coarse vegetation was multiplied by 0.05℃.

3.3.5. Runoff Mitigation

Runoff mitigation was calculated as the percent of rain absorbed in a vacant lot during a 24hour, 5 inch rain event. The USDA Soil Conservation Service (SCS) runoff curve number (CN) is assigned to each lot based on combinations of hydrological soil group and landcover according to the methodology developed in USDA TR-55 (USDA, 1986) that is widely used to predict runoff from rainfall. Hydrologic Soil Groups are derived from the NYC soil survey (New York City Soil Survey Staff, 2005) through an overlay analysis in ESRI ArcGIS 10. To utilize the sampled data for this purpose, vacant lots were classified into three major usage categories (open space, impervious area, residential area) based on the "actual use" observations, then we reclassified each of these groups to comply with the USDA (1986) sub-categories (residential, poor, fair and good open space, paved and bare soil) based on our sampled landcover areas. Next, we assigned SCS CN to the different combinations of landcover/hydrologic soil group as shown in Table 4. Runoff and potential retention were calculated based on the methodology outlined by USDA (1986, chapter 2); we calculated the potential maximum retention under the assumption of a 5 inch rain event. A 5 inch rain event was selected based on rainfall isopleths maps in USDA TR-55, to exemplify a significant rain event that is not rare (5-10 year event). Similar to Whitford et al. (2001), we use as an indicator a 'runoff retention coefficient' that represents the proportion of precipitation that will be retained during a 5 inch rain event. Total retention for each lot was calculated by multiplying the coefficient by lot area and rain event.

Table 4: Summary of SCS curve numbers by landcover

	Landcover\Hydrologic Soil Group	**A**	**B**	**C**	**D**
1	Residential	77	85	90	92
2	Open space poor (>50% cover)	68	79	86	89
3	Open space fair (50-75% cover)	49	69	79	84
4	Open space good (<75% cover)	39	61	74	80
5	Paved	98	98	98	98
6	Bare soil	72	82	87	89

3.3.6. Habitat

Four indicators including habitat availability, connectivity, sensitivity, and shape, were used to evaluate the quality of habitat provisioning for biodiversity of each of the sampled lots. Connectivity was calculated as the distance to other green areas in the city using the "Near" tool in ESRI ArcGIS 10 with a search buffer of 500 meters. A green layer that includes all major known green and open spaces in NYC was created by merging available GIS green infrastructure layers including federal and state recreation and non-recreation open space, NYS Department of Conservation land, and NYC parks and other open space. GIS layers were obtained from the NYS GIS Clearinghouse (http://gis.ny.gov/) and the NYC OpenData (https://nycopendata.socrata.com/) websites.

Sensitivity is defined as a binary indicator suggesting whether a vacant lot is located within a designated "ecological priority area" or not as defined by New York State Department of Environmental Conservation (2009) and The Nature Conservancy (n.d.). Shape is defined as a measure of the relative compactness of each lot. Compactness was determined using ArcGIS tool Shape Metrics Tool (Parent, 2011), which provides a way to measure a polygon's likeness to a circle. A circle was used as the ideal shape because it minimizes habitat edge to interior ratios (Smith et al., 2006), therefore providing an indicator of habitat quality. We assessed the vacant lot shape as compared to likeness to a circle, a common way of measuring the compactness of polygons (Angel, et al., 2010). Compactness values calculated by the Shape Metrics Tool are given on a 0-1 scale, where 1 is the most circle-like.

3.3.7. Size

Values of one through ten were assigned to the total size of green, brown and blue landcovers in each lot. Because our sample included a small number of very large lots with very wide dispersion, we grouped lots in the highest five percent of green, brown and blue landcover area into the tenth category. We performed sensitivity tests on the exclusion percentage, and found that 5% was the lowest exclusion percentage that produced the closest approximation to a normal distribution. Remaining data were classified into nine categories using Jenks optimization algorithm.

Table 5 shows the percent of the distribution of total green, blue and brown land area for our vacant lot sample data.

Table 5: Lot green, brown and blue landcover area distribution

Category	Number of Lots	Percent of Total
1	324	22%
2	175	12%
3	167	11%
4	255	17%
5	165	11%
6	164	11%
7	82	5%
8	61	4%
9	29	2%
10	80	5%

3.4. Evaluation of Social Indicators

We selected socioeconomic indicators that reflect social need for ES in the vicinity of vacant lots. Since vacant lots themselves provide limited insight into the socioeconomic characteristics of the neighborhood, social indicators are evaluated based on a neighborhood analysis. The definition of a neighborhood for the purpose of ES analysis is little studied, but insight can be drawn from the more expansive literature on walking behaviors and proximity to green space. Suggested distances for a neighborhood analysis range 300-1000 meters (Colabianchi et al., 2007; Hörnsten et al., 2000). In this study, we tested three different proximity definitions by analyzing all social indicators for which we had data for a neighborhood buffer of 300, 500, and 750 meters. For brevity, we report only the results using the 500 meter buffer.

Four indicators of social need were established and calculated from publically available Census and City data in the neighborhood of the sampled vacant lots – median household income, median real estate values, population density, and density of green and open space. Median household income and real estate values are commonly used indicators in studies of the relationship between socioeconomic status and various environmental issues (e.g. locations of contaminated sites or correlation with green spaces) (Grove et al., 2006; Mennis, 2002; Talen, 2010; Troy et al., 2007). Population density is a measure of the quantity of the population that potentially benefits from ES (Talen, 2010), and green space density is used to indicate the current level of availability and access of these services. Table 6 summarizes the indicators and data sources used in our calculations. The Model Builder tool in ArcGIS 10 was used to perform an iterative analysis in which a buffer was drawn around each lot and the social need indicators were evaluated within the buffer. We structured the indicators in our combined social-ecological valuation so that social value was represented by social need for ES. Thus, low household income, low real estate value, and low green space density correspond to high social value (e.g. high social need) while low population density correspond to low social value (e.g. low social need).

Table 6: Summary of socioeconomic indicators

	Indicator	Data
Household income	Average median household incomes of block groups within 500 m of lot	U.S. Census, NYC MapPLUTO
Real estate values	Average median real estate values of block groups within 500 m of lot	U.S. Census, NYC MapPLUTO
Population density	Average population densities of block groups within 500 m of lot	U.S. Census, NYC MapPLUTO
Green space density	Average open space densities of block groups within 500 m of lot	NYC green layer, NYC MapPLUTO

3.5. Combined Social-Ecological Valuation

To combine social and ecological values of sampled vacant lots across the city, all indicators were rescaled from their organic unit into a standard scale of 1-10 and then weighted. All ES indicators were grouped and weighted equally. Each ecosystem service group was weighted as one, and if more than one indicator was used to evaluate an ecosystem service, weight was distributed equally on the different indicators. Defining the weights for each assigned indicator is a crucial task in creating an integrated evaluation mechanism for ecosystem service. To-date there is little agreement on methods and tools for determining weights, but there is a growing recognition that such methods are essential (Felix et al., 2011). Some ways the issue of weighting ES has been resolved in the past include expert and public stakeholder engagement (Bryan et al., 2011; Calvet-Mir et al., 2012) or weighting systems based on existing literature (Hepcan et al., 2011). For the purpose of demonstrating a social-ecological approach to ES stacking methods in NYC we chose to initially weight all indicators equally. After social and ecological values were weighted and summed, the resulting number was assigned a High or Low value, based on whether it was above or below the data median. Social and ecological values were then classified into four combined groups of social-ecological values as shown in Table 7.

Table 7: Social-ecological matrix

Social	Ecological	group
High (H)	High (H)	4
Low (L)	High (H)	3
High (H)	Low (L)	2
Low (L)	Low (L)	1

4. Results and Discussion

4.1. Vacant Lots Typology

Results of our vacant lot assessment revealed that the dominant landcover type in the sampled vacant lots was fine vegetation (54%), followed by coarse vegetation (29%), then paved surface (6%) and building cover (3%), with water accounting for only 1% of total area of the sampled vacant lots. The lots in the top five percent of area (i.e. large lots) in green, blue and brown landcover accounted for 77% of total land area in the sample, as well as more than fifty percent of each landcover category. Vacant lot land area was distributed heterogeneously across the five boroughs, with 63% of the vacant lot land in our sample being concentrated in Staten Island, 23% in Queens and less than 10% in each of the other three boroughs. Landcover types were also distributed heterogeneously across the five boroughs. For example, most building cover was concentrated in Brooklyn vacant lots, while most bare soil was concentrated in Manhattan vacant lots. Notably, there was high variance in the area of fine and coarse vegetation of sampled vacant lots, but only in Staten Island and Queens. Figure 1 shows comparative land area in each landcover type across boroughs.

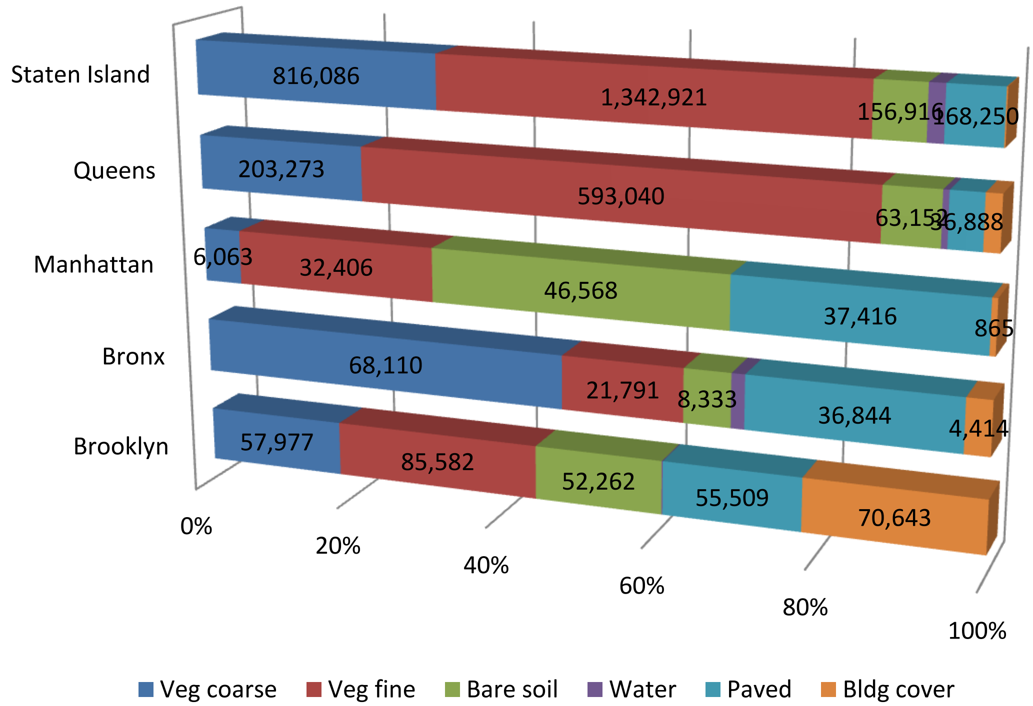

Figure 1: Distribution of landcover in vacant lots in the five boroughs of NYC (N=1,502). Area is represented as percentage of the total area within each borough and labels show the total area in square meters.

4.2. Ecosystem Benefits of Vacant Lots

Given that vacant lots in the city tend to be dominated by vegetated landcover, these sites can be considered a valuable source of regulating ES, including carbon sequestration and storage, air pollution removal, localized cooling effects and stormwater management. Based on the assumptions and methods outlined above, we estimated total carbon and air pollution removal for the sample population of vacant lots, as well as means and medians on a per lot basis. We also estimated cooling effects and stormwater management at the lot level (Appendix A: Table A-1).

Our results indicate that surveyed vacant lots stored between 3.01E+07 and 3.78E+07 kgC. Scaled up to the entire city vacant lots stored a total of between 5.97E+08 and 7.48E+08 kgC. Similarly, sampled vacant lots sequestered between 9.95E+04 and 1.37E+05 kgC/yr, and the total population of lots was estimated to sequester between 1.97E+06 and 2.72E+06 kgC/yr. For air pollution we found that tree cover in vacant lots absorbed a total of between 3.21E+08 and 4.01E+08 kilograms of air pollution (including CO, O_3, PM_{10}, SO_2, and NO_2). We also found that vacant lots in NYC were cooled between 1.3 and 1.61℃ by coarse vegetation on a per lot basis. This estimate does not account for cooling effects of trees on surrounding lots and therefore captures only a highly localized cooling effect. Since prioritizing green infrastructure (the dominant landcover type in sampled vacant lots) for stormwater absorption is a major priority in New York City (New York City, 2010), we calculated storm water runoff infiltration rates and found that 37% of the rain in a 24 hour, 5 inch rain event, could be retained by the sampled vacant lots as they currently exist. This translates to total stormwater retention of 38 m^3 of rain in such a rain event (Appendix A: Table A-1).

In our surveyed lots, 59-74% was covered with trees, vegetation or bare soil, providing a diverse habitat matrix for biodiversity. Additionally, many of the sampled lots (197) are located within areas defined as sensitive ecosystems by The Nature Conservancy. We were also interested in location of lots with ecological value in the overall matrix of ecosystem patches in the city. Median distance to other green spaces, indicating support of connectivity between patches, was 454 meters. Lots were found to be relatively compact with regard to shape with an average score of 0.68 on the compactness metric (Appendix A: Table A-2). We also evaluated food provisioning of vacant lots since some lots were active community gardens, as well as public access and ownership type as indicators of the potential for vacant lots to provide cultural services (Appendix A: Table A-3).

Social indicators in the neighborhoods around sampled vacant lots suggest that lots are mostly located in areas of high population density (median of 12,033 people\sq km) and well below the city average median household income. Average median household income in the neighborhood around the surveyed vacant lots is $42, 581, while the city's average is $50,285 (US Census, n.d.). Green density, indicating the relative availability of green space in these neighborhoods was also relatively low with a median value of 5%. Detailed results and summary of statistical descriptors of ecological and social indicators are presented in Appendix A.

4.3. Mapping Social-Ecological Systems

Since ecological and social values are calculated and attributed to a specific lot, we are able to map the quality of ecosystem services and level of social need spatially across the city. This spatially explicit method afforded the opportunity to compare and identify important areas for conservation and priority areas for urban planning based on the site specific conditions of low ecological value and/or high social need. The spatially explicit results of the ecological assessment of runoff mitigation, carbon storage, habitat provisioning, and air pollution removal are demonstrated in Figure 2. Results are mapped as scaled indicators on a scale between 1 and 10. The UES value maps exemplify an important observation regarding ecosystem services in the context of planning and urban governance, namely, that there are tradeoffs and synergies among various ES, and planners often need to choose which service to maximize in a particular planning scenario. In Figure 2 we see that areas that are most significant for habitat or carbon storage are not necessarily those best suited to maximizing runoff mitigation. This particular result is mainly due to the fact that soil type is major factor in the ability to absorb rain, while carbon storage is driven by vegetated landcover and habitat by both landcover and proximity to other habitats. In similar manner, when mapping social indicators of social need (Figure 4), it is clear that different measure of social need have varying spatial distribution. While access to green spaces (or the lack of it) is evident across the five boroughs, high social need indicated by the population density and median income indicators are more concentrated in specific boroughs and in local neighborhoods within the boroughs.

4.4. Multi-criteria Stacking of Social and Ecological Value

While mapping ecological and social indicators separately is heuristically interesting and provides some utility, a more challenging task involves evaluating the overall value of multiple indicators within the 'social' and 'ecological' categories, and the way they interact across space.

Figure 2: Google Earth Images of surveyed vacant lots. The lots exemplify the four classes of results presented in Table 7.

We recognize the complexities and difficulties in aggregating variable ES, nonetheless, we also recognize the importance of advancing ES stacking methods for the purposes of planning and decision making and suggest a novel multi-criteria, combined social-ecological ES assessment method. In Figure 5 we presents the spatially explicit results of the methodological steps involved in weighting and grouping the social and ecological ES indicators described in section 3.5. Four classes of results are created by dividing the aggregated social and ecological indicators into high and low categories that indicate the level of social need in conjunction with ecosystem services quality (see Figure 2 for examples of lots with different class configurations). For example, H-H represents high social need in conjunction with high level of ecosystem services. Examining these locations further may offer insight into the interaction of areas of high social need with their urban ecology and may provide useful insight into the governance mechanisms relevant to the management of vacant lots. On the other hand, L-H lots represent low social need and high level of ecosystem services. Many of L-H lots are located in Staten Island, characterized by predominantly middle class population with relatively low population density and the most green space of any of the five city boroughs. We found that H-L lots (high social need in conjunction with low level of ecosystem services) to be the most interesting category in terms of providing a novel information source for planning and decision making. Lots with high social need combined with low existing ecological value could present an important opportunity for developing underserved vacant land areas into spaces that better provide ecosystem services and meet neighborhood social needs. For example, H-L lots could be developed as priority green infrastructure areas by turning them into community gardens or urban pocket-parks. If developed appropriately, these lots provide critical opportunities to improve sustainability and resilience of the NYC social-ecological system. Vacant lot development could involve significant social-ecological transformation through directly addressing the social need for green space and other ecological, cultural and social services via green infrastructure development. As the map in Figure 5 demonstrates, most of the lots in the H-L class are concentrated in the well-known underserved urban neighborhoods including Harlem in Manhattan, the south Bronx and parts of Brooklyn. L-L lots (with both low social need and low ecosystem services) are also interesting for their potential to be transformed from underdeveloped spaces in the city into spaces that provide increased ecosystem service provisioning such as storm water absorption and habitat for biodiversity.

4.5. Identifying Clusters

In order to better identify urban areas of potential interest to planners in NYC, we identified spatial hotspots of vacant lots that shared both proximity and specific social-ecological characteristics such as high social need and low ecosystem service provisioning. Identification of clusters of vacant lots with similar characteristics provides an important use of spatially explicit data from our high-low social and ecological indicators and enables, in addition to the identification of particular lots, the identification of vacant lot areas with significant social-ecological transformation potential. Using the Getis-Ord Gi* HotSpot analysis tool in ESRI ArcGIS 10, we identified areas that have statistically significant ($p<0.01$) clustering of high social need and low ES values (H-L), and then intersected them to identify areas of high-low clustering. Figure 6 demonstrates the results of the social-ecological indicator hotspot analysis with major clusters found in the Bronx and two areas at the center and south of Brooklyn. The results of the Getis-Ord Gi* statistic are reported through a Z score. The Z score represents the statistical significance of clustering for a specified distance that is based on Randomization Null Hypothesis computation.

Overlaying the clustering results with a zoning map of New York City reveals that the majority (88%) of lots in the H-L clusters are located in residential areas, of them 60% are located within high density residential areas (R6-R10 in NYC zoning codes) and 28% are located in lower density residential areas (R1-R5 zoning codes). Only 22 lots (10%) within the H-L cluster are located in manufacturing zoning. The finding that most H-L clusters are located in residential areas is important because it demonstrates that social-ecological transformation could actually be realized through urban policy and planning, as opposed to the obvious disincentives for transforming vacant land located in predominantly industrial zones. However, the high social need found in H-L lots may be due to the inherently low income and property values in manufacturing areas and represent one of the challenges in this analysis- the sensitivity of the results to the ranking and weighting scheme. If population density were weighted more heavily in our analysis, lots in manufacturing areas would most likely disappear from the clusters. Nonetheless, the clustering results support our multi-criteria social-ecological valuation findings in that significant clustering of low quality ES occur in places of high social need for these services and demonstrate the utility of our ES stacking and evaluation methods for uncovering overlooked priorities for urban planning for urban sustainability and resilience.

Figure 3: Spatially explicit mapping of indicators of ecological value in a sample of vacant lots in NYC

Figure 4: Spatially explicit mapping of indicators of social value for ecological services within a radius of 500 meters around sampled vacant lots. In this map, high social need is considered high social value.

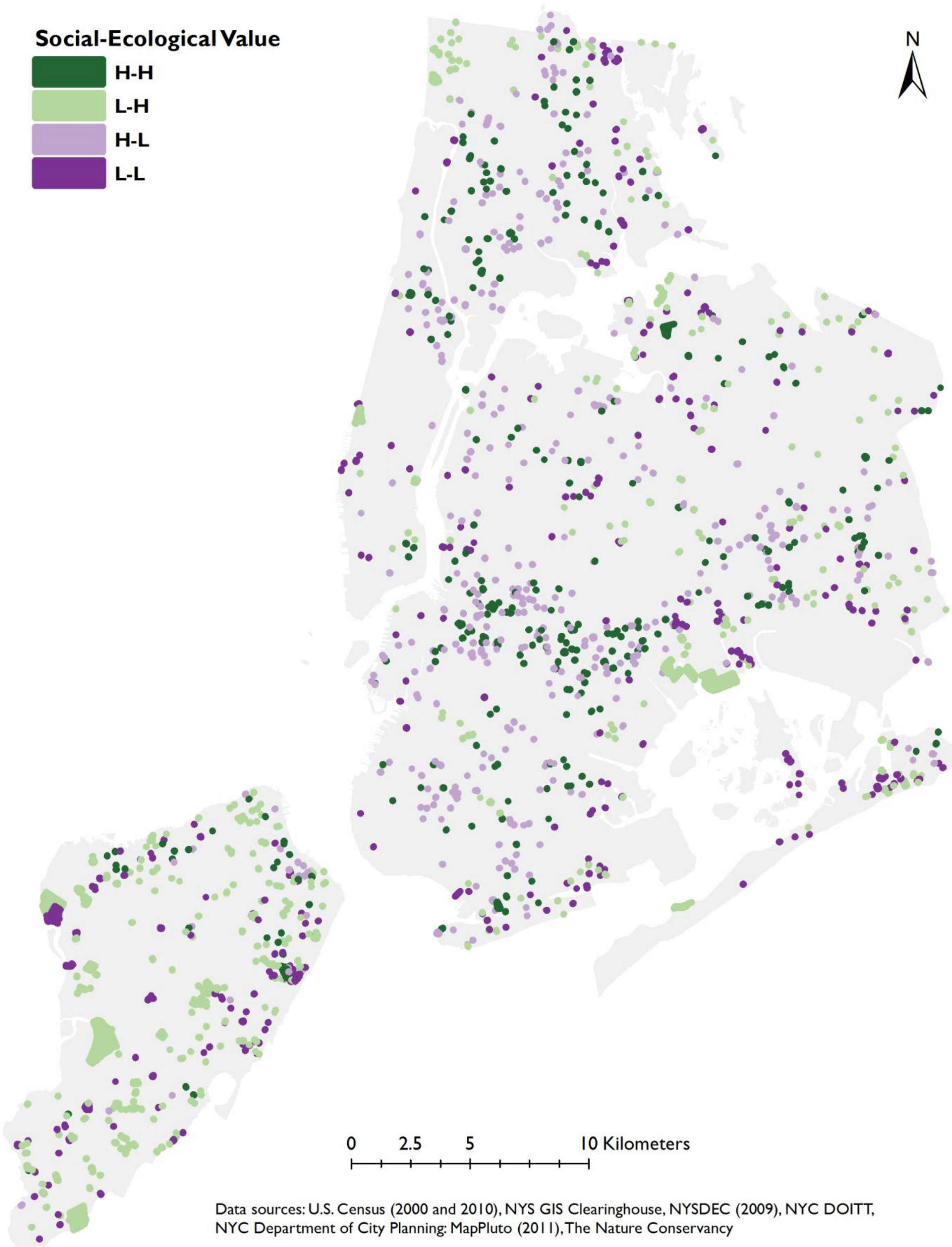

Figure 5: Combined social-ecological value of vacant lots in NYC

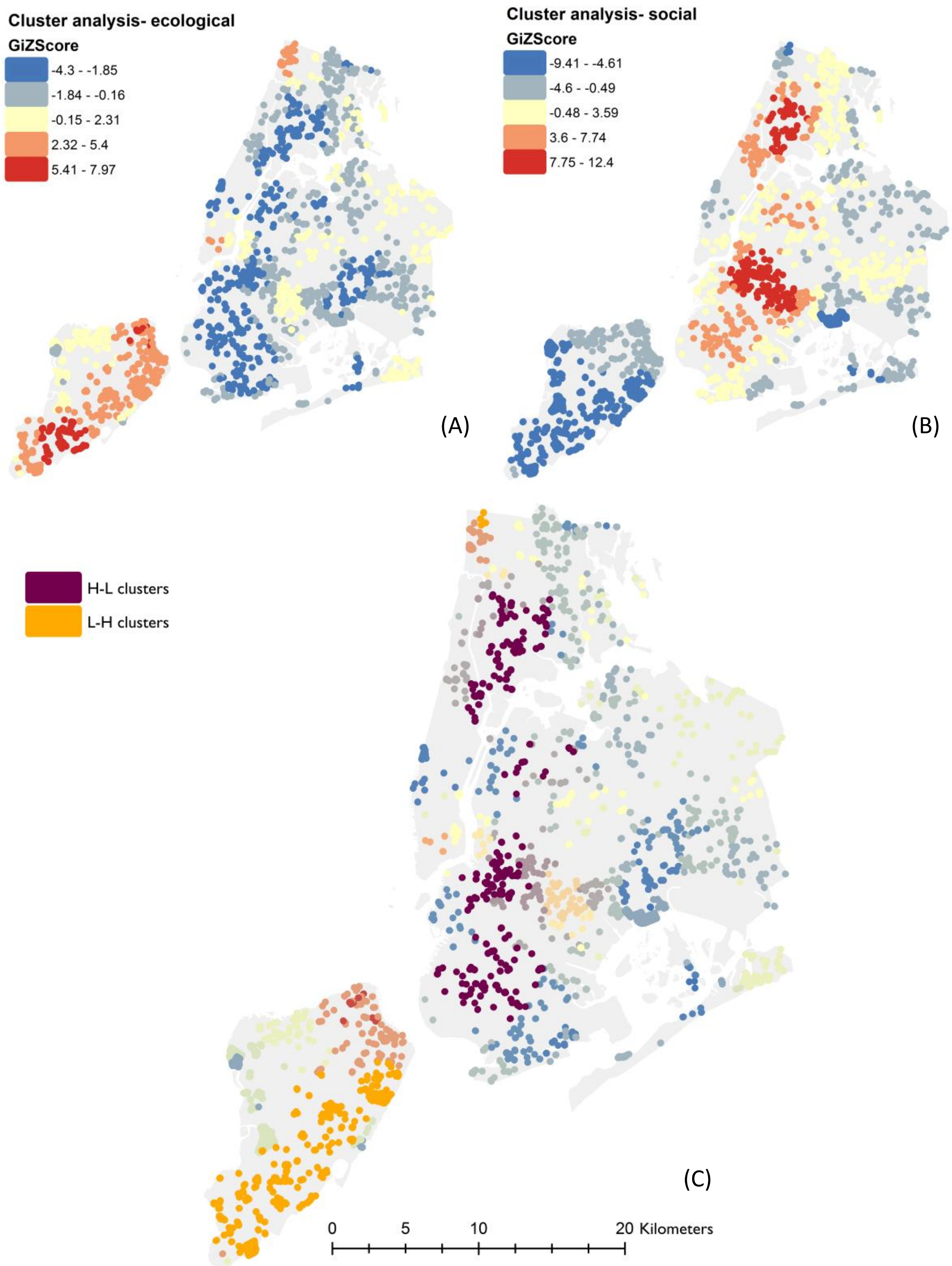

Figure 6: High-Low social-ecological clusters. A) cluster analysis of ES values; B) cluster analysis of social need; and C) combined social-ecological overlay of cluster analysis. H-L clusters represent areas where social has significant high Z scores and ES have significantly low Z scores. These areas can be identified as priority areas for ecosystem planning in vacant lots.

4.6. Limitation of the Research

Limitations of this study include data availability, and conceptual and methodological issues. The accuracy of ecological indicators is only as good as the accuracy of the landcover data and many ancillary data sets and GIS layers. These datasets may or may not be available in different locations and when available, may not be at the appropriate spatial resolution. For example, one of the early barriers for the development of this research was lack of publically available landcover data for New York City, which prompted the use of the random survey using Google Earth. Due to the spatial heterogeneity of the urban landscape, high spatial resolution is a matter of necessity. The continued development of such datasets and their growing availability will make spatially explicit social-ecological urban systems more widely feasible.

An important conceptual issue is the aggregation of social and ecological indicators in a multi-criteria analysis. While we demonstrated the importance and usefulness of aggregated social-ecological mapping, inherently, the methodology requires the obfuscation of the details of the specific indicators, inhibiting the ability to account for tradeoffs and synergies. To overcome this limitation, the interplay between the aggregated data and particulars of specific locations can be developed. For example, a comparison between adjacent lots or lots located in palaces of interest can provide a more detailed assessment. The spider diagram in Figure 7 exemplifies the multivariate nature of the indicator stacking and provides one possible way to evaluate and compare characteristics of different lots. Here, we present lots that fall within the four classes of social-ecological values. It is clear from the image that a particular class membership can be driven by different score compositions. For example, lots 1 and 3 both represent high social need. However, in lot 1 this is driven by population density, while in lot 3 it is driven by the lack of green space.

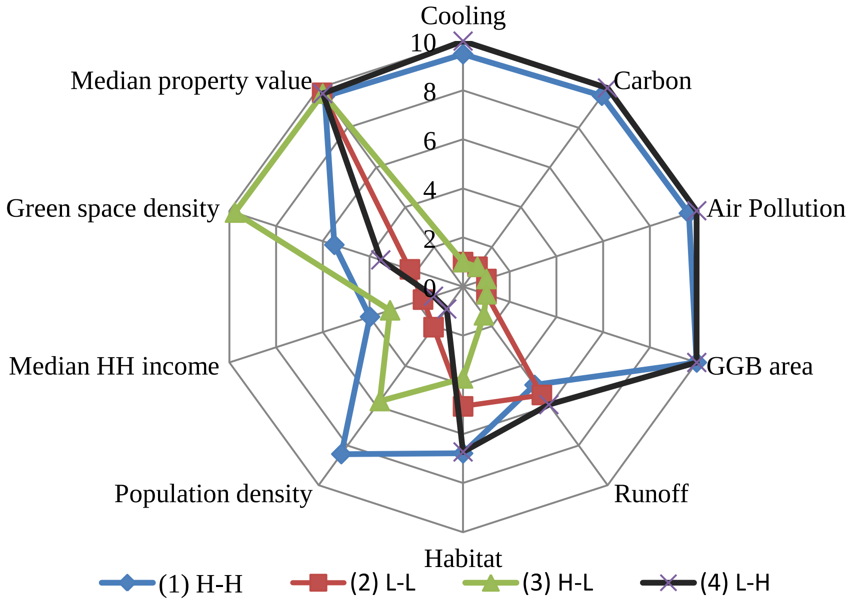

Figure 7: example of multivariate representation of social and ecological indicators for selected vacant lots (one from each quadrant)

A significant methodological difficulty includes the stacking of ecological and social indicators by the assignment of weights. While the assignment of weights is likely to remain a normative process, more research is needed to establish best practices for determining appropriate weighting mechanisms in various situations. Another methodological issue is the sensitivity of the High-Low quadrant analysis to the definition of the midpoint, because it offers only a coarse classification of the data. Further research is required to evaluate this sensitivity and its impact on research results given that this coarse breakdown is one of a few ways to represent spatially and visually the conjunction of social and ecological phenomena. It is important to continue to develop social-ecological indicator stacking to provide opportunities to develop dynamic scenario modeling of change under different global change, urbanization, and development scenarios, which are essential for the development of the study and practice of urban resilience.

5. Conclusion

Among the many categories of urban infrastructure in the city, vacant lots provide a heterogeneous matrix of social-ecological patches that provide multiple ES. Spatially explicit analyses of social-ecological systems enables the quantification of ecological and social variables in ways that can serve as useful tools for visualization, for stacking ecosystem services, and for planning and decision making purposes. Our goal has been to understand the combined social-ecological value of complex urban patches in order to illuminate overlooked patches in the city where policy and planning could simultaneously meet combined biodiversity habitat and ecosystem service provisioning and social justice goals.

Mapping stacked UES involved linking social, biological, and infrastructural heterogeneity in a spatially explicit conceptual framework. We used a multi-criteria social-ecological valuation approach to urban ecosystem services assessment where high/low social value and high/low ecological value are generated for each vacant patch. Our results indicate that urban land is indeed highly heterogeneous, in particular with respect to social need for, and spatial variation in, ecological services. A map of combined social-ecological value demonstrates how our methodological approach can illuminate opportunities for social-ecological transformation in the urban landscape. Sampled vacant lots in New York City were often located in conjunction with social demographic and economic characteristics that imply a need for ecosystem services, suggesting a novel opportunity for urban policy and planning to develop vacant land in ways that enhance ecosystem service provisioning, especially in hotspot locations with high social need and low ecological value.

A concerted effort by the city and grass-roots organizations and individuals to convert underutilized vacant land into green infrastructure with social-ecological amenities could provide increased resilience to predicted near-term effects of climate change (New York City Panel on Climate Change, 2009) including offsetting predicted increases in stormwater and urban heat. Improving social-ecological resilience in NYC includes the need to increase opportunities for social networking and cohesion and increased interaction between urban residents and urban ecosystems (McPhearson et al., in press), which vacant lot development could address. Using vacant land for social-ecological transformation has the potential to increase the overall sustainability of the city through provisioning increased green space for urban gardening, recreation, habitat for biodiversity, carbon and air pollution absorption and other regulating, provisioning, and cultural ecosystem services.

Future research directions should include development and comparison of different weighting systems to evaluate their impacts on our overall results. We plan to expand our analyses from discrete vacant spaces to include contiguous green infrastructure patches at multiple scales across the city and the metropolitan region. As we make progress toward baseline citywide ecosystem services assessment, we will be able to provide critical input to the city on priorities for urban biodiversity conservation and ways to expand the provisioning of ecosystem services. However, though providing a baseline ecosystem services assessment across spatial scales is a laudable short-term goal, understanding the effects of urbanization and regional and global drivers of environmental change on ecosystem services requires a temporal dimension as well. Improved knowledge of the linkages between biodiversity and the potential for ecosystem services can be generated by thoughtfully planned future land use and management scenarios using some of the approaches we have discussed above. Spatially explicit mapping at high resolution allows visualization of stacked ecosystems services which can provide increased awareness at local and regional level of the benefits of biodiversity and ecosystems services for urban areas, especially the full suite of services provided by green infrastructure. This knowledge can help to reinforce the understanding of the co-dependency of urban social-ecological dynamics and their impacts on the surrounding landscape, its biodiversity and the interactions between urban, peri-urban and rural areas. It is important to further refine methods for stacking monetary and non-monetary values of urban ecosystem services to support policy decision-making and increased capacity of local governments and communities to incorporate urban biodiversity and ecosystem services values in planning and management.

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Appendix A: Detailed social-ecological evaluation results

The following tables A-1 through A-4 summarize findings of the social and ecological assessment of services and indicators. Where meaningful, values and indicators were scaled up from the sample population to total population. Table A-1 provides total estimated carbon and air pollution ecosystem service values at both the sample and population level, as well as measures of central tendency for all ecosystem services. Habitat indicators are summarized in Table A-2, including area and proportion of area in green, blue, and brown landcover; compactness; connectivity and sensitivity. Cultural and provisioning services and indicators, which include total number and percent of total lots which are publicly-accessible, city-owned or being used for food production, are shown in Table A-3. (Values in Table A-3 are relevant to the sample only.) Social indicators of need, summarized in Table A-4, were estimated within a 500-meter buffer of each sampled vacant lot. These include household income, population density, property value and green density.

Table A-1: Regulating ecosystem services

		Total		Mean	Median
		Sample (N=1,502)	Population (N=29,782)	per lot (N=1,502)	per lot (N=1,502)
CARBON	Carbon Sequestration (kg/yr/m^2)	9.95E+04 - 1.37E+05	1.97E+06 - 2.72E+06	66 - 91	3-6
	Carbon Storage (kg/ m^2)	3.01E+07 - 3.78E+07	5.97E+08 - 7.48E+08	20,061 - 25,134	1,661 - 2,099
AIR POLLUTION	SO_2 (g/yr/m^2)	2.32E+06 - 2.86E+06	4.59E+07 - 5.67E+07	1,541 - 1,905	112 - 145
	NO_2 (g/yr/m^2)	6.48E+06 - 7.76E+06	1.28E+08 - 1.54E+08	4,315 - 5,163	290 - 390
	PM_{10} (g/yr/m^2)	4.37E+06 - 5.45E+06	8.65E+07 - 1.08E+08	2,907 - 3,629	213 - 281
	O_3 (g/yr/m^2)	2.54E+06 - 3.50E+06	5.03E+07 - 6.93E+07	1,689 - 2,327	88 - 160
	CO (g/yr/m^2)	4.81E+05 - 6.62E+05	9.53E+06 - 1.31E+07	320 - 441	16 - 30

Cooling Effects (℃)		---	---	1.3– 1.6	.7 – 1.1
STORM WATER MANAGEMENT	Proportion of Rainfall Retained	---	---	37%	33%
	Volume Rainwater Retained (m^3)	---	---	38	10

Table A-2: Habitat Indicators

Statistic	N (Population)	Green, Blue & Brown Land Area (m^2)	Proportion Green, Blue & Brown Landcover	Compactness (scale: 0-1 where 1=most compact)	Proximity to other green spaces (m)	Number of lots with Sensitive Habitat	
						TNC	DFW
Mean	per lot (N=1,502)	1,943 – 2,405	59 - 74%	.68	527	---	---
Median	per lot (N=1,502)	156 - 202	70 – 96%	.65	454	---	---
Total	Sample (1,502)	2,918,469 - 3,611,792	---	---	---	197	11
	Population (29,782)	57,814,269 – 71,549,709	---	---	---	---	---

Table A-3: Cultural and Provisioning Services/Indicators

	Public Access	City-Owned	Food Provision
Total # of lots (N=1,502)	80	340	26
Percent of total (N=1,502)	5%	23%	2%

Table A-4: Social Indicators of Need (within a 500 meter Buffer of Lot)

	Median Household Income ($)	Average Population density	Median Property Value ($)	Green Density
Mean	42,581	12,984	52,254	11%
Median	40,900	12,033	34,583	5%