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The overlooked role of New York City urban yards in mitigating and adapting to climate change

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There is a dearth of research focusing on the role that urban residential open space plays in climate change adaptation, despite evidence suggesting that environmental benefits accrue when even small pockets of open space are made permeable and vegetated. In densely built New York City, there are 21,448 ha (53,000 acres) of such land. One city block with adjoining contiguous open space was investigated to quantify its existing environmental value and also its potential to provide enhanced services through redesign. The study block's open space was found to be 35% permeable and planted with 96 trees, storing 45,359 kg (100,000 lb) of carbon. Simulations conducted using the United States Environmental Protection Agency Stormwater Management Model contrasting normal, light, and heavy precipitation years suggested that increases in annual precipitation could be fully mitigated by reducing impervious surface cover by 25%. The preservation of the existing vegetated residential urban open space and the conversion of paved surfaces to a pervious condition both appear to be effective strategies for enhancing the city's ability to adapt to and mitigate for climate change.

Keywords: sustainability; climate change adaptation; land cover change; green infrastructure; storm water management

1. Introduction

While cities, projected to house 67% of the world's population by 2050 (United Nations 2012), have embarked upon climate change mitigation and adaptation initiatives, most sustainability research, and related city planning and policy focus on new, large-scale development, publically owned open space (Design Trust for Public Space 2005, Peper *et al*. 2007, PlaNYC Sustainable Stormwater Management Plan 2008) or reconfiguration of derelict urban areas (ODPM 2003). The positive environmental values of pervious urban residential open spaces are often overlooked, as are the environmental losses associated with the vegetation loss and paving over of small plots of already-developed urban residential land (Mathieu *et al*. 2007).

Urban soils and trees have the potential to store carbon, improve air quality, and manage storm water (Nowak *et al*. 2006, Peper *et al*. 2007, Pouyat *et al*. 2006, Blanusa 2011). Conversely, the loss of pervious urban surfaces has negatively impacted habitat suitability,

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biodiversity (Nowak *et al*. 2006, Haase and Nuissl 2007, Pouyat *et al*. 2006, Scalenghe and Marsan 2009), and energy exchanges resulting in the urban heat island effect (Whitford *et al*. 2001, Gil *et al*. 2007).

At least 3642 ha (9000 acres) of New York City's land area were converted from vacant land to impermeable buildings, roads, and parking lots over the last 25 years (PlaNYC Sustainable Stormwater Management Plan 2008). However, it is not known how much residential yard space has been gradually covered in hardscape. Loss of urban open space is not easily quantified for multiple reasons – open space in densely built urban areas is often hidden from public view behind buildings; satellite imagery cannot always distinguish between concrete and permeable open space (Mathieu *et al*. 2007, Perry and Nawaz 2008); property owners pave small yard space without undergoing permitting processes rendering city records incomplete; and access to private property for field studies is difficult to obtain. The potential for enhanced ecosystem services, such as stormwater management, temperature regulation, and air quality improvement, to occur by removing impervious surfaces within small urban residential lots is thus poorly understood.

Addressing this gap, this paper analyses land use and ecological service functioning at the block scale, with a focus on New York City. We focus specifically on contiguous yards forming a green corridor located behind nineteenth-century row houses and early twentieth-century apartment buildings. Like the Australian suburban study conducted by Ghosh and Head (2009), which focuses on the sustainability potential related to "traditional" and "modern" buildings and their surrounding gardens, we look at urban pre-World War II row house and 8–10 storey apartment structures and adjacent open space. The density of the NYC block necessitates *in situ* analysis enhanced with computer-based methodology.

This study has three principal goals. First, we aim to achieve a more fine-grained picture of the current environmental value of pervious surfaces and trees planted on the block perimeter (street trees) and the block core (front and back yards of row houses and apartment buildings). Second, we seek to more fully understand the additional environmental benefits that would accrue if the existing hardscape on private yards was removed and replaced with pervious surface cover and vegetation. Third, we discuss implications for a holistic land-use policy to "encourage and reward 'synergies' and 'co-benefits'" of sustainable land management as promoted by United Nations Human Settlements Programme (2011) to expand the climate change preparedness strategy toolbox.

2. Background and context

A total of 21,448 ha (53,000 acres) (Solecki and Patrick 2008) of residential open space remain today in New York City – more than one-quarter of the city's total land area, 62 times the size of Central Park and almost twice as much as all New York City parkland combined. The most densely built city in the USA, New York City houses over 8 million people (US Census 2010) on about 78,104 ha (193,000 acres) of land. Our study block is located in Manhattan, the smallest but most densely built city borough (sub-division), comprising almost 7.5% of the borough's total area (Table 1).

Planned in 1811, the Manhattan grid influenced the planning and development of countless other cities throughout the country. City blocks measure approximately 61 × 244 m (200 × 800 ft) and house lots 30 m (100 ft) deep by 5.5–7.6 m (18–25 ft) wide (Figure 1). Even after significant post-war development combining lots to create multi-family apartment buildings, many NYC residential neighbourhoods continue to be characterised by nineteenth-century row houses, having small front areaways and rear yards. Many of these open areas were paved over time, resulting in a significant loss of the pervious surface cover.

Table 1. Summary of open, private, yard, and residential space in New York City, by Borough (Solecki and Patrick 2008).

	NYC	Manhattan	Bronx	Brooklyn	Queens	Staten Island
Total area (ha; acre)	78,808 ha; 194,739 acre	5900 ha; 14,581 acre	10,982 ha; 27,138 acre	18,539 ha; 45,811 acre	28,395 ha; 70,166 acre	14,990 ha; 37,043 acre
Per cent of New York City	100.00%	7.49%	13.94%	23.52%	36.03%	19.02%
Open space (ha; acre)	45,760 ha; 113,077 acre	2486 ha; 6145 acre	6475 ha; 16,002 acre	9148 ha; 22,606 acre	16,880 ha; 41,713 acre	10,769 ha; 26,611 acre
Per cent of total borough area	–	42.14%	58.96%	49.35%	59.45%	71.84%
Per cent of total NYC area	58.07%	3.16%	8.22%	11.61%	21.42%	13.67%
Private open space (ha; acre)	21,849 ha; 53,991 acre	740 ha; 1831 acre	2566 ha; 6343 acre	4319 ha; 10,674 acre	8488 ha; 20,975 acre	5733 ha; 14,167 acre
Per cent of total borough area	–	12.56%	23.37%	23.30%	29.89%	38.24%
Per cent of total NYC area	27.72%	0.94%	3.26%	5.48%	10.77%	7.27%
Yard space (ha; acre)	27,529 ha; 68,026 acre	1224 ha; 3027 acre	3562 ha; 8804 acre	5464 ha; 13,504 acre	9737 ha; 24,061 acre	7539 ha; 18,630 acre
Per cent of total borough area	–	20.76%	32.44%	29.48%	34.29%	50.29%
Per cent of total NYC area	34.93%	1.55%	4.52%	6.93%	12.36%	9.57%
Residential yard space (ha; acre)	21,139 ha; 52,236 acre	840 ha; 2077 acre	2605 ha; 6438 acre	4319 ha; 10,674 acre	8035 ha; 19,857 acre	5337 ha; 13,190 acre
Per cent of total borough area	–	14.24%	23.72%	23.30%	28.30%	35.61%
Per cent of total NYC area	26.82%	1.07%	3.31%	5.48%	10.20%	6.77%

2.1. Storm water impact of urban yard space

Like many other cities planned prior to the early twentieth century, New York City's combined sewer system was originally designed to convey urban runoff and wastewater together to local waterways. Starting in the 1890s, interceptor pipes were installed to redirect this

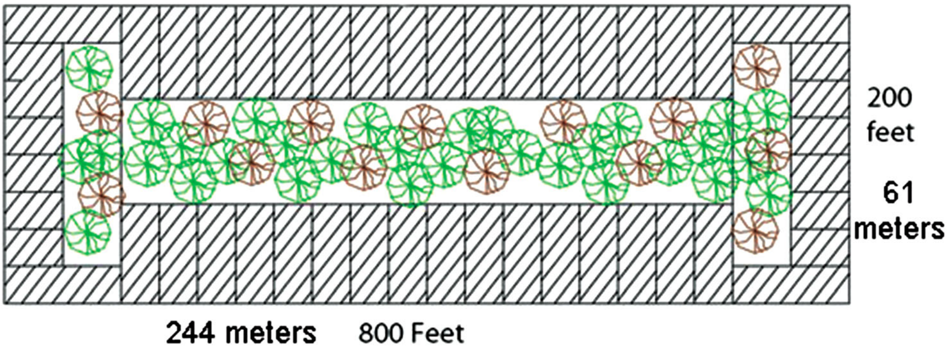

Figure 1. Dimensions of a typical Manhattan Block.

combined waste to newly constructed treatment plants, from which the treated water was discharged to nearby tributaries and estuaries. As urbanisation proceeded, additional impervious surface cover reduced the amount and capacity of soil to filter and absorb rainwater that, in turn, increased the hydrologic load on the collection system. Because of this infrastructure history and configuration, wet weather runoff causes combined sewer overflow (CSO) events, augmenting pollutant loads to receiving waters and creating public health risks (Riverkeeper 2007, PlaNYC Sustainable Stormwater Management Plan 2008). In 2006 alone, 27 billion gallons of untreated combined sewer and rainwater were released into New York City's waterways (Riverkeeper 2007). These CSOs are the leading cause of waterway pollution, potentially creating health hazards, damaging fish habitat, debilitating harbour navigation, and negatively impacting water-based recreational activities (Riverkeeper 2007).

In 2008, New York City adopted PlaNYC, the city's blueprint for sustainability. The New York City Panel on Climate Change (NPCC 2010) linked climate change to extreme weather events experienced in New York City and projected a 5–10% increase in baseline rainfall by 2100. Since heavier precipitation will amplify the burden placed on the ageing sewer system, the city developed PlaNYC Sustainable Stormwater Management Plan (2008) and the NYC Green Infrastructure Plan (2010) to improve water quality in part by managing storm water at its source rather than relying exclusively on "grey" infrastructure to convey and treat water.[1] Storm water source control and green infrastructure approaches, in combination with more traditional grey infrastructure strategies, can also play a role in climate change adaptation (Gill *et al*. 2007).

Opportunities to expand green infrastructure are of particular relevance in New York City where precipitation is often intense and heavy (NPCC 2010), especially compared, for example, to the northwestern US precipitation, which experiences more frequent, but also less intense precipitation (Gallo *et al*. 2012).

2.2. *Tree planting in green streets/green yards*

Trees and vegetation are known to enhance ecosystem service functioning, lower surface and near-surface temperatures, and helping to mitigate for some of the effects of climate change (Nowak *et al*. 2006, Rosenzweig *et al*. 2006, Peper *et al*. 2007, Perry and Nawaz 2008). Consequently, New York City committed to planting one million trees by 2030 to maximise environmental benefits, to offset street tree mortality, and to mitigate for anthropogenic greenhouse gas emissions associated with building, energy, and transportation activities (PlaNYC 2007). There are over 5.2 million trees in New York City[2] (Nowak and Crane 2003), about half of which are managed by NYC Parks and Recreation Department (Peper *et al*. 2007). The other half of the city's urban forest is located on semi-public space, private open land, cemeteries, private commercial, industrial, and residential parking lots.

Computer simulation programs such as i-Tree Streets and UFORE (developed by the US Forest Service) quantify the costs and benefits, such as stored and sequestered carbon dioxide, air quality impacts, and energy savings (largely due to tree canopy), of different species and size trees. These models have been applied to urban tree studies in many US cities, including New York (Nowak *et al*. 2006, Peper *et al*. 2007), Chicago (USDA 2009), and Boise (Peper *et al*. 2007). However, most of these *in situ* analyses focus on public property and/or large swaths of private property, and only peripherally on high-density, ground-level (as opposed to rooftop) vegetation on existing residential lots. For these reasons, little in-depth micro-spatial vegetative analysis of residential land in densely built parts of cities like New York is currently available.

3. Methods

A residential, 15,221 m^2 (163,840 ft^2) study block in a historic district of Manhattan was chosen to investigate the existing and potential enhanced services that could be provided by pervious residential yards. This block, like many New York City row house blocks, has rear yards behind buildings and smaller front areaways. Because satellite imagery only provides limited land cover resolution in densely built areas, 70% of the study block private yards were accessed through the dwelling or viewed from adjacent backyards. Each yard space was measured, its surface cover type and percentage noted, and the number, species, type, and size of each tree diagramed.[3]

The backyards of the 44 row houses in the study block are 5–6 m (18–20 ft) wide and about 11 m (35 ft) deep. Behind each of the three early twentieth-century apartment buildings are "alley yards" of paved open space, approximately 4.6 × 38 m (15 × 125 ft) in the area. The area of the entire block is just over 15,176 m^2 (3.75 acres), with total yard space – paved or unpaved – measuring 3926 m^2 (0.97 acre) or 27% of the block. Cumulatively, the backyards represent 3480 m^2 (0.86 acre) of contiguous open space, providing adjoining landmass for vegetation, habitat, storm water infiltration, and other ecological service functioning. Seen from a bird's eye view, the block grid creates unique microclimates of adjoining lots of open space hidden from the street view, shaded by surrounding taller structures (Figure 2).

Ecosystem services were evaluated using i-Tree Streets, a computer modelling tree analysis tool developed by the US Forestry Department. Storm water impact was simulated using the United States Environmental Protection Agency (USEPA) Stormwater Management Model (SWMM). Photographic documentation was obtained during site visits and building residents informally surveyed.

3.1. Quantifying storm water impact of urban yard space

To assess extant and future potential for urban yards to reduce storm water runoff, a series of simulations were performed using the USEPA SWMM. SWMM is an industry standard model used by cities like New York to quantify the impacts of changes in land use and infrastructure on rates and volume of combined sewage generated from urban surfaces.

A SWMM model was created to quantify the volume of runoff generated from a 74.32 m^2 (800 ft^2) yard under a range of imperviousness, infiltration, and precipitation

Figure 2. Private trees in study block core. Photo credit: author.

conditions. The surface condition of the portion of the lot that was not occupied by a building varied from 100% impervious to 100% pervious. The infiltration capacity of the permeable spaces was allowed to vary from a heavily compacted condition (represented with an SCS Curve Number of 98) to a well-tilled condition (CN = 66).[4] Three different hourly precipitation time series were also considered reflecting average (1988), above average (2011), and below average (2001) annual precipitation amounts.

3.2. Quantifying tree values

To obtain a fine-grained analysis of tree count and associated benefits, the size and species of study block trees on both private and public property were surveyed and results entered into i-Tree Streets, a modelling programme devised to understand structure of street trees, their associated ecosystem services, and to assist municipalities in urban forestry management and cost–benefit analysis (US Forest Service 2009). Only larger trees were analysed by the software program – small trees, shrubs, and other vegetation not visible across property lines were not input into the modelling programme, although they were noted.

While i-Tree was developed principally to analyse public street tree function, in this study the same software was used to evaluate the benefits of trees planted on private residential yard space. The model is free, user friendly, and requires input parameters that could be readily generated for the study area. It can be run using either a sample or the complete tree inventory to quantify environmental and aesthetic value. iTree quantifies air quality benefits conveyed by trees through their ability to reduce temperature (via shading and evapotranspiration), remove, intercept, or store air pollutants such as carbon dioxide (CO_2), nitrogen dioxide (NO_2), ozone (0_3), sulphur dioxide (SO_2), and particulate matter (PM10). Negative attributes of trees, such as biogenic volatile organic compounds that contribute to ozone formation, and planting and maintenance costs, are subtracted from benefits to arrive at a generally comprehensive benefit–cost analysis of the urban forest.[5]

Storm water management co-benefits and costs are estimated as trees convert soil moisture into vapour through evapotranspiration and rainwater is conveyed by soil and tree roots, reducing peak flows and reducing the runoff load on combined sewer systems; aesthetic and property values are also considered in the benefit–cost analysis.

3.3. Community input

The team distributed project description leaflets at each garden-level apartment and contacted residents by phone when possible to request access to private yard space. Each building was visited at varying times in order to reach residents who work. Once permission to access the property was granted, the team endeavoured to take measurements and photographs as quickly and as accurately as possible, acutely aware that in researching private property, opportunities to revisit the site are rare. Not all residents wanted to engage in conversation,[6] but those who did were informally questioned to learn how the yards were used, how intrinsic they were to the desirability of the living space, and evolution of landscape design and historical planting.[7]

4. Results

4.1. Storm water impact of study block yard space

The SWMM simulations of the study block underscore the value of pervious yards in mitigating for increases in annual precipitation, as could potentially occur as a result of climate change (Figure 3). During 1988, a year until recently considered to represent historical average rainfall conditions in New York City (113 cm or 44″ precipitation annually), a completely impervious 74.32 m^2 (800 ft^2) yard yielded approximately 1586 m^3 (0.42 million gallons) of runoff per year. If annual precipitation is increased, for example to 2011

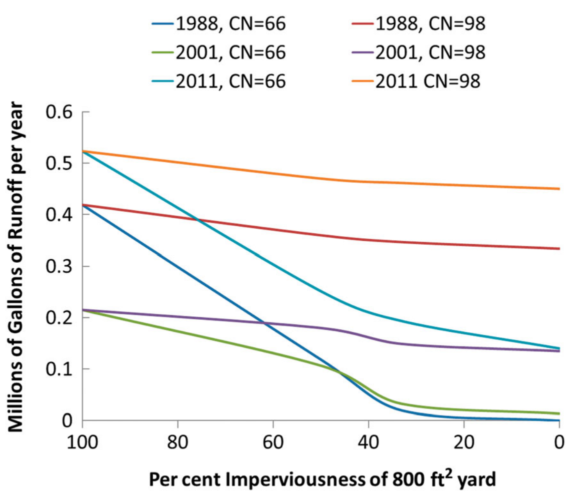

Figure 3. Stormwater runoff volume of previous surfaces.

amounts (185 cm or 73″ annually) – the year that NYC experienced Hurricane Irene, the same impervious yard would yield approximately 20% more storm water or about 1981 m^3 (0.52 million gallons). Figure 3 suggests that the increase in annual precipitation and associated runoff could be fully mitigated by increasing the percentage of the yard that is covered by high-quality pervious spaces by only 25%. That is, a 75% impervious yard would have yielded the same volume of annual runoff during 2011 that a 100% impervious yard would have yielded during 1988.

The SWMM simulations estimated that the permeable yards reduced runoff by about 1015 m^3 (268,202 gallons) in 2011, lowering the total volume of runoff of the entire block by about 58%, compared to blocks with fully paved lots. The modelling results suggest that every 0.93 m^2 (10 ft^2) of impervious yard space that is replaced with high-quality pervious surfaces can reduce the yard's storm water footprint by about 1.4%.

The results underscore the storm water benefits already realised by urban yard spaces as well as their potential for enhancement if the existing hardscape were removed and replaced with high-quality, pervious surfaces.

4.2. Value of trees planted on public versus private land

Nowak and Crane (2003) sampled 206 plots (0.04 ha or 0.1 acre each) in NYC, estimating that approximately 1,500,000 trees exist in residential open spaces; however, only 76 residential lots were included in the sampling, potentially underestimating the number of trees in small, densely packed row house and apartment blocks.

A snapshot study of the trees on the block found a total of 96 trees almost evenly divided between those on the public street (47) and those planted on private property (49). Tree heights within the backyard block core range from seedlings (uncounted in our study) to 15 m (50 ft) tall; street tree heights ranged from 3 m (10 ft) to 15 m (50 ft). While there were a similar number of private and public trees, i-Tree modelling found that the private trees provided about 72% of the net carbon benefits (via sequestration, avoidance, maintenance and decomposition releases) than were provided by the street trees[8] (Table 2). Trees with greater canopy were mostly planted along the study block street, and have more significant biomass, net carbon, storm water, and air quality benefits (Nowak and Crane 2003, McPherson *et al*. 2007, Peper *et al*. 2007). With the exception of the American Elm, trees found behind buildings generally provided less canopy cover and appear to exist by either by design of individual owners or as "volunteers", compliments of random spread of seeds by birds and wind.

The greatest environmental performer planted on block was the American Elm that sits midblock in the private block core, annually reducing energy costs by $44, improving air quality (saving $11/yr), and reducing storm water costs by over $13/yr (through intercepting 16,702 l (4500 gallons) annually. The elm was also the best energy performer, providing $44 value annually in gas and electric savings due to summer time cooling; it also provided twice the energy benefit of the highest performers planted on the street, the pin and white oaks at $20 each. The next most important environmental performer in terms of rainfall interception (16,615 l) and carbon storage (averaging 2467 kg) was the Honey Locust, planted on the public street. In total, the 47 street trees benefitted the city by almost $2500 annually, while the 49 trees planted in the block core benefitted the environment by $1688/yr.

i-Tree Streets was developed in part to aid benefit–cost decision-making to determine if costs associated with planting and management justified expenditure of public funds. Since costs of planting, maintaining, pruning, and irrigating private trees are borne by the property

Table 2. Annual CO_2 net benefits and stored CO_2.

Species	Sequestered (kg)	Decomposition release (kg)	Maintenance release (kg)	Avoided (kg)	Net total (kg)	Total (kg)	% of total tree numbers
Annual CO_2 releases, reductions and net benefits private trees, by species						Stored CO_2	
Birch, paper	152.12	−27.72	−4.29	874.11	1176.76	1200.94	16.33
Dogwood	242.73	−50.04	−6.44	458.42	935.95	2186.96	14.29
Maple, Norway	282.77	−94.43	−4.29	482.08	1005.46	4127.04	8.16
Serviceberry, other	65.17	−7.27	−2.34	155.16	288.92	317.57	8.16
Maple, amur	23.41	−2.62	−0.98	44.89	92.79	114.61	6.12
Tree of heaven	133.20	−16.76	−3.51	728.65	1001.42	732.37	6.12
Witch hazel	21.82	−2.23	−0.98	52.54	97.34	88.35	6.12
Spruce, other	20.31	−1.65	−1.76	87.86	129.13	72.18	6.12
Cedar, atlas	39.14	−2.29	−0.62	32.18	68.41	218.54	4.08
Magnolia, other	102.22	−9.09	−1.15	138.18	230.15	874.51	4.08
Mulberry	128.68	−22.67	−1.77	272.75	376.98	2180.13	4.08
Plum, purpleleaf	64.76	−5.89	−0.80	56.50	114.57	566.59	4.08
Maple, red	4.19	−0.15	−0.09	2.43	6.38	6.98	2.04
Hornbeam, American	37.95	−3.70	−0.53	61.69	95.41	355.53	2.04
Redbud, eastern	2.77	−0.09	−0.09	3.12	5.71	4.48	2.04
Holly species	87.22	−14.36	−0.89	94.28	166.26	1380.53	2.04
Pear, callery	71.80	−4.29	−0.09	58.90	126.32	412.68	2.04
Elm, American	262.71	−55.05	−1.60	274.40	480.46	11,645.40	2.04
Total, private	1742.94	−209.73	−18.79	2305.22	3819.63	20,133.34	100.00

Annual CO_2 releases, reductions and net benefits of public trees, by species						Stored CO_2	
Ginkgo	274.39	−34.25	−5.05	399.96	635.05	3,292.82	19.15
Pear, callery	597.48	−65.92	−0.80	627.94	1,086.91	6,338.58	19.15
Planetree, London	263.02	−30.05	−4.52	659.83	888.28	2,887.41	17.02
Honeylocust	361.94	−53.33	−3.90	703.02	1,007.73	5,128.29	12.77
Linden, other	295.22	−36.58	−2.93	284.13	539.85	3,514.06	12.77
Redwood, dawn	9.12	−0.11	−0.27	54.24	62.99	5.18	6.38
Oak, white	259.20	−33.47	−1.77	271.81	495.76	3,218.55	4.26
Oak, pin	259.20	−33.47	−1.77	271.81	495.76	3,218.55	4.26
Coffeetree, Kentucky	3.04	−0.04	−0.09	18.08	21.00	1.73	2.13
Oak, northern red	16.55	−0.88	−0.27	22.75	38.15	84.81	2.13
TOTAL, Public	2,339.16	−288.11	−21.36	3,313.58	5,271.48	27,689.99	100.00

Table 3. Annual dollar value of 96 trees on block.

	Private trees	Street trees	Total on block
Property and aesthetic	$1096.06	$1627.63	$2723.69
Air pollution removal	$87.40	$121.07	$20.87
Annual CO_2	$28.57	$39.43	$‘68.00
Stored carbon	$150.60	$207.12	$357.72
Storm water	$127.45	$80.44	$207.89
Energy (electrical, gas)	$396.48	$554.12	$950.60
Sub total	$1839.55	$2676.82	$5182.37
Total adjusted for costs not incurred by the city	$2505.55	$2676.82	$5182.37

owner (and not the city), our study adjusted the i-Tree dollar output, subtracting those costs from the private trees since those expenses are not borne by the city (Table 3). If private costs are "backed out", the environmental benefits cost analysis indicates that the value of the 49 private trees ($2505) is still exceeded by the 47 public trees ($2676.82).

4.3. Landscape design and community engagement

The majority of rear yards had centred hard surfaces (concrete, bluestone, brick, and wood decking) bordered by planting along the outer edges; one yard had a small fountain and another had a stepped rock garden leading to the subterranean basement level. Yards averaged about 36% permeable open space; seven yards had more than 50% pervious cover. Shade-tolerant small ornamental shrubs such as rhododendron, azalea, euonymus, and box and flowers predominate in private yards that provide maximum aesthetic value but less canopy cover to permit light to enter living spaces.

About 50% of the yards visited showed evidence of regular maintenance. Owners were more likely to tend to gardens than were tenants, although both tenants and owners used yard spaces regularly. At least two residents planted herbs or edible vegetables; only one resident composted food scraps on-site due (others indicated interest in doing so but were concerned about attracting rodents). Garden spaces were often used for holding small summer parties or play areas with basketball nets or other sports equipment; religious events are also celebrated in two yards every fall.

One 60-unit apartment building co-op board in the study wanted to take advantage of the paved, narrow "alley yards" located behind their building to provide enhanced outdoor areas to fold laundry and socialise, steps from their apartment doors. They created an in-house green committee, developed building rules allowing access, limiting hours and uses, to the paved alley behind their building. They introduced container plants and outdoor furniture (not having the budget to remove the pavement) and developed a maintenance schedule distributing the labour. A local green jobs programme was engaged to plant and maintain green space in front of their building, thus supporting the local economy.

While the NYC Department of Environmental Protection distributes free rain barrels across the city, no rain barrels were installed for storm water capture – a missed opportunity since each yard featured exterior gutters and leaders. Two residents expressed interest, but were discouraged by the difficulty in finding fittings compatible with older leaders, limited space to accommodate rain barrels, and a NYC law requiring a licensed plumber perform downspout disconnects.

As might be expected in densely built Manhattan, some residents indicated occasional annoyance with neighbours' children, dogs, or upkeep of their yard space, including concern about overhanging tree limbs or dilapidated fences dividing property lines. However, almost all residents indicated that outdoor access was a significant attraction and reason for choosing to live adjacent to urban yard space. Despite accounts of occasional friction between neighbours, anecdotal evidence gathered during the study supports empirical findings that psychological benefits accrue when people are exposed to open, greened space – even *looking* at trees has been shown to reduce stress, increase focus, and enhance sense of well-being (Kaplan and Kaplan 1989).

5. Discussion

The NYC Department of Parks and Recreation has selected tree species that provide significant canopy, can survive in the harsh urban environment and grow to significant stature, enhancing neighbourhood streetscape. While many inner block trees were planted for aesthetic reasons and are not, on average, as environmentally beneficial as street trees, the diversity of tree species planted on private yards builds resilience to disease and blight. The i-Tree analyses and SWMM modelling reveal the cumulative value of the block open spaces and suggest that urban yards cumulatively play a significant role in climate change adaptation and mitigation strategies through carbon sequestration, air quality enhancement, and storm water management.

While not in the scope of this study, the diverse benefits of increased vegetation and permeable surfaces as part of an effective urban heat island mitigation strategy are widely acknowledged (Akbari *et al*. 2001, Nowak *et al*. 2006, Montalto *et al*. 2007, Peper *et al*. 2007, Riverkeeper 2007). Rosenzweig *et al*. (2006) found that vegetation and street trees convey a greater cooling potential per unit area than living roofs or light surface cover and point to the importance of neighbourhood conditions when ranking urban heat island mitigation strategies and recommended that installing vegetated or light roofs should be a priority strategy in densely built Midtown Manhattan. Indeed, the energy exchange impact of residential yard spaces should be studied further by measuring surface and near-surface temperatures on row house and low-scale apartment blocks with varying amounts of paved and vegetated surfaces.

There is considerable evidence to suggest that open space, especially vegetated open space, increases property value (National Park Service 1992, Design Trust for Public Space 2005). One NYC study finds that living near community gardens raises property values by as much as 9.4% in the 5 years after opening, with the greatest benefit seen in disadvantaged neighbourhoods (Been and Voicu 2006). McPherson *et al*. (2007) find increased property values of buildings on blocks shaded by street trees in the borough of Queens, likely due to added curb appeal. Increased property values translate into higher tax revenues reaped by the municipality and higher resale value realised by property owner and real estate community alike. In New York City, rents can be as much as 25% higher where there is access to private green space (Piazza 2011), though appraisal value varies widely depending on neighbourhood characteristics, real estate market, condition of open space and the presence of other amenities. Just as market forces have spurred new, luxury development, that feature on-site gyms, play areas, green roofs and parking lots, and extant paved exterior space, can be greened as a building amenity, boosting economic value.[9]

Ghosh and Head (2009) highlights the importance of local cultural factors in developing sustainability policy. Hanging laundry, no matter how practical and energy saving, is not likely to be embraced by New Yorkers since this practice is inconsistent with local custom. Three trends evident in New York City suggest that property owners might well be amenable to greening heretofore impervious residential open space: the burgeoning urban farming and community garden movements and localised efforts to reduce building flooding and sewage backup in flood-prone areas. These grass-roots efforts provide opportunities to educate New Yorkers about environmental and quality of life benefits of removing hardscape and enhancing residential open spaces. Apartment and row house dwellers may spend their private dollars on low-impact development strategies if they were encouraged; indeed, some building owners already do spend money resurfacing and redesigning urban yard spaces, without being aware of potential climate change adaptation strategies that could be employed. An aggressive expansion of community-based green jobs programmes providing green infrastructure training could make affordable services more widely available also stimulating the local economy.

The NYC Department of Environmental Protection has begun to reach out to private property owners to encourage storm water management best practices, but contacting hundreds of thousands of property owners is a significant undertaking. Enforcing regulations when yard spaces are hidden from the public view is also difficult. Therefore, an aggressive and widespread incentive and voluntary education programme could be undertaken to encourage: (1) maintaining and preserving extant vegetative surface cover, using soil that is amended with organic matter to increase permeability and infiltration rates, (2) removing hardscape and replacing with pervious surfaces, (3) planting resilient native species, scaled for small spaces, and (4) disconnecting downspouts and installing rain barrels to capture and reuse rainwater from rooftops.

Innovative policies and legislation that incentivise the removal of hardscape and discourage the paving of existing open space could be implemented, such as tax abatements, more stringent permitting requirements, and expansion of water and sanitary fee discount programmes.[10] A formal and extensive surveying of New Yorkers to better understand barriers to maximise climate change adaptation practices could be undertaken to inform communications efforts. Taken together with education, communication and training plans, incentives and legislation could build upon extant community gardening and urban farming trends, spurring more widespread adoption of climate change adaptation and mitigation strategies on private urban land.

6. Conclusion

The 21,448 ha (53,000 acres) of the urban residential yard space already provides myriad opportunities to manage storm water, reduce summer time temperatures, support habitat, and enhance air quality and quality of life. Furthermore, the resulting benefits *can be expanded* if hardscape is removed and replaced with high-quality soil and vegetative cover. In effect, urban yard space provides a canvas on which climate change resilience and adaptation occur. The snapshot of just one New York City block – one of thousands – suggests that the aggregate environmental and economic value of pervious open space should be included in a broad climate change and adaptation mitigation strategy.

Rising urban temperatures, increased storm events, costs of infrastructure maintenance, and construction suggest that we can no longer afford to ignore the cumulative environmental contributions of the urban residential yard space. In the face of considerable challenges posed by climate change, increased urban population, building density, and an ageing wastewater treatment system, multi-tiered and diverse adaptation strategies should be adopted, including maximising the environmental benefits of small pockets of residential open space.

Notes

1. The NYC Green Infrastructure Plan (2010) defines grey infrastructure as traditional constructed infrastructure, such as pipes, underground storage tanks, and treatment plants. Green infrastructure encompasses strategies such as green roofs, bio-swales, and rain gardens.
2. However, hundreds of city trees are lost annually due to storm damage, development, high mortality rates of young, newly planted trees, and tree ageing.
3. While researchers could view 100% of the yards, the type of surface cover was not always evident from a distance.
4. While urban soil is considered relatively compact (National Resources Conservation Group, USDA 1966), the soil infiltration rates measured in three study block yard spaces exceeded 10.2 cm (4 in.) of rain/hour; these filtration rates were twice the rate associated with many permeable pavement options.
5. See Peper *et al*. (2007), Nowak and Crane (2003), and the i-Tree Streets Users Manual (2009) for more information with regard to the rationale, functioning, strengths, and limitations of the software modelling program.
6. A privacy agreement was signed in which the team pledged not to reveal the location or release photographs with addresses.
7. Remnants of two formal English gardens remaining from the early part of the twentieth century bore witness to perhaps the first New York City "garden movement" that oriented townhouses towards backyard spaces, once they were no longer needed for domestic purposes (Dolkart 2009).
8. This model does not account for the additional value of soil and vegetation other than trees that is found in the block inner courtyard – a comparison that is not applicable to the street tree modelling.
9. Indeed an advertisement for an apartment in the very building in our study features an online picture of the introduced seating areas and large planters in the previously unused alley-yard behind the building.
10. Many US cities, such as Philadelphia and Seattle adjust storm water fees based on the surface cover, but these measures do not extend to small, private residential urban lots.

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