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Valuing green infrastructure in an urban environment under pressure — The Johannesburg case

Alexis Schäffler [a,*], Mark Swilling [b,c,1]

[a] Gauteng City-Region Observatory, a Partnership Between the University of Johannesburg, University of the Witwatersrand, Johannesburg, and the Gauteng Provincial Government, South Africa
[b] Sustainability Institute, University of Stellenbosch, PO Box 12358, Die Boord 7613, South Africa
[c] MPhil in Sustainable, Development, Planning and Management at the School of Public Leadership, University of Stellenbosch, PO, Box 12358, Die Boord 7613, South Africa

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ABSTRACT

This article considers the importance of robust planning for green infrastructure in fast changing Southern African cities. A key theme is the extent to which ecosystem services are valued publicly, and the opportunity costs of not investing in the green infrastructure. We explore green infrastructure through pairing insights of social–ecological resilience with perspectives on urban infrastructure transitions. By converging these views, we show how green infrastructure can be viewed as an innovative response to challenged urban environments.

Through a Johannesburg case study, a number of ecosystem services constitute sources of resilience for an otherwise constrained city. While this is positive and to be valorised, many South African cities are in the midst of service delivery protests, so that resilient ecosystems, and the citizen networks that sustain these, are largely overlooked in planning processes.

This article offers three key conclusions. First, a proper understanding of green infrastructure requires blending insights from social–ecological system thinking and infrastructure transition scholarship. Second, there is a paucity of knowledge around ecosystem services in Johannesburg, and that the planning to facilitate ecosystem service valuation is largely inadequate. Third, addressing this requires ecosystem valuations relevant to the unique conditions in developing world cities such as Johannesburg.

1. Introduction

With 61% of its population living in urban areas, Southern Africa is the most urbanised subregion in Africa (UNHabitat, 2010). Sub-Saharan Africa also has the fastest growing urban population among developing regions, followed by South and Central Asia (Angel et al., 2011). Although the momentum of demographic growth is slowing in Africa, as is the case globally, massive rural to urban migration continues as a defining trend, shaping ever-larger cities that are often poorly equipped to accommodate new arrivals (Sanyal, 2011).

62% of all Sub-Saharan urban dwellers live in largely non-serviced slums, reflecting the ongoing urbanisation of poverty and social insecurity (UNHabitat, 2010). This is perhaps the most striking representation of a global infrastructure crisis that has beset an increasingly resource-constrained world. The stark contradiction, that large parts of the urban world lack the infrastructure required for a quality of life equivalent to that found in developed world cities, but where provision of the requisite infrastructure will dramatically exacerbate global resource-pressures, has prompted a growing body of scholarship on urban transitions towards sustainability (Hodson and Marvin, 2009; Krausmann et al., 2008; Smith et al., 2005). Although the work on urban infrastructure transitions is a welcome response to the infrastructure crises facing fast-growing cities, it has been oriented largely towards the question of how to reduce resource consumption and improve resource efficiency through the redesign of infrastructure (Brunner, 2007; Hodson and Marvin, 2010; Weisz and Steinberger, 2010), and tends to focus on the so-called ‘grey infrastructure’ networks of energy and material supply systems (Weisz and Steinberger, 2010). The literature has largely overlooked the importance of urban biophysical networks – what could be termed ‘green assets’ or ‘green infrastructures’ – that provide ecosystem services critical to enhancing cities' resilience.

Our view is that the failure to consider green assets as equally important to cities' networked grey infrastructures is an omission from two perspectives. First, it neglects the role of urban ecological assets in generating a range of ecosystem services (Jansson, 2013-this issue). While there has been significant progress in ecosystem valuation studies, insights from this work have not translated into studies on whether and/or how ecological assets are being taken into account by authorities responsible for planning a city. More research is needed on the way in which ecosystem services are being, or ought to be valued in cities,

* Corresponding author at: Private Bag 3, Wits, Johannesburg, South Africa. Tel.: +27 828757285; fax: +27 11 717 7281.
E-mail addresses: alexis.schaffler@gcro.ac.za (A. Schäffler), Mark.Swilling@spl.sun.ac.za (M. Swilling).
[1] Tel.: +27 21 881 3196.

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with a specific focus on how they might conceivably be incorporated into spatial planning and urban design, as well as financial accounting and public-asset management frameworks.

Second, there has been little if any attention paid to how urban green assets function as an economic driver by means of the community social networks, business value chains and household property investment decisions that are constituted wherever these assets are developed and maintained (Ernstson et al., 2010a). The extent to which cities are giving due recognition to the positive economic impacts from green infrastructure projects warrants deeper investigation.

Writing from a developing country, we are sensitive to the particular dynamics that characterise Southern African cities, where research into, and planning around, environmental issues in general are both in their infancy (Simon, 2010). In these cities, environmental concerns are largely absent from academic, policy and even civil-society activist discourse, being dwarfed by the seemingly more pressing matters of service delivery deficits, economic exclusion and poverty. Certainly, there is work that takes its impetus from the concern that much urban development in Sub-Saharan Africa is proceeding through the rapid and widespread conversion of natural areas into urbanised land, where vegetation is being replaced with built forms – often continuous, low-density sprawl – without greenways, natural urban drainage systems, or riparian zones (de Lange et al., 2009; OECD, 2011; Palmer et al., 2004). But this work falls short of assessing how green infrastructure is or is not being counted as an asset worth building and maintaining in the fabric of fast-growing cities, both from an ecosystem service and economic development perspective.

This paper builds an argument that rapidly expanding cities such as those in Sub-Saharan Africa urgently need to consider the importance of green assets as part of their broader infrastructure development programmes; that this will only happen if the value of the ecosystems services provided by these assets are formally recognised in city budgeting and accounting systems; and if the ecological economy of citizen greening networks is integrated into city-planning processes. The argument proceeds through three steps. First, insights from two theoretical traditions – social–ecological system thinking and infrastructure transition scholarship – are combined to construct an intellectural model for green infrastructure. Second, we use a case study of Johannesburg, one of the largest and fastest growing cities in Africa, but one with a unique ecological asset in the form of an urban forest, interspersed with green spaces and gardens, to explore how green assets could be, and then whether they are being, adequately valued by city authorities in charge of seriously challenged urban contexts. Third, we use insights from the case study to suggest innovative ways for how green infrastructure can be factored into public asset management and economic planning frameworks.

2. Theoretical Framework: Green Infrastructure

According to Kambites and Owen (2006), green infrastructure is the "connected network of multifunctional, predominately unbuilt, space that supports both ecological and social activities and processes". Green infrastructure includes street trees, private and public gardens, parks, riparian zones along urban drainage lines, undeveloped ridges, and a variety of urban agricultural spaces such as food- and community-based gardens.

While green features and spaces can be found in all cities, to a greater or lesser extent, it is not a given that these will be regarded as green infrastructure. The defining contribution of a green infrastructure approach is that it sees ecological and natural assets as infrastructure, equivalent to water or power networks, for example, that provides multiple social, environmental and economic functions (Landscape Institute, 2009).

Green space systems need to be conceived as green infrastructure in the same way as other built infrastructures, so that they can be designed and developed to function as a whole, rather than as a set of separate unrelated parts (Barthel et al., 2005; Benedict and McMahon, 2002). They need to be 'formalised' as a coherent object of planning. As Wolf (2004) states: "A city would never build a road, water or electrical system piece by piece, with no advanced planning or coordination. Green infrastructure is the idea that nature in cities should be administered in an integrated way, just as grey infrastructure systems have been."

To achieve this, two schools of thinking are combined. These are discussed below as: (1) unlocking the ecosystem services potential of urban green spaces, and (2) infrastructure transitions for increased urban resilience. When brought together these two streams of thinking offer a new perspective on how rapidly urbanising regions can better adapt to confluence of urban challenges.

2.1. Unlocking the Potential for Urban Green Spaces

Amidst unprecedented urbanisation, the role of cities in influencing the capacity of ecosystems to sustain societal development and to generate ecosystem services is increasingly being recognised (Alberti et al., 2003). This recognition is rooted in a social–ecological system approach to cities, which depicts cities as closely coupled human–nature systems whose institutional adaptability to environmental feedbacks is a critical determinant for enhancing urban resilience (Barthel and Isendahl, 2013-this issue; du Plessis, 2008). As defined by Folke et al. (2010), a social–ecological system is an "integrated system of ecosystems and human society with reciprocal feedbacks and interdependence. The concept that emphasises the humans-in-nature perspective".

Social–ecological system analysis has stimulated new thinking about the relationships that exist between people and biophysical processes in cities (Bai et al., 2010). This is based on the metaphor of resilience, defined by Folke et al. (2005) as the potential of a system to absorb disturbance re-organise, i.e. the capacity for self-organisation. Socio-ecological resilience thus relates to the mutual adaptability of both social and ecological systems, which determines the ability of a complex system to absorb disturbance and re-organise in the face of pressures (Barthel, 2008; Ernstson, 2008; Folke et al., 2005). Applying this metaphor, Ernstson et al. (2010b) explain that reducing resilience exposes systems to greater risks, uncertainties and surprises, whereby it takes progressively smaller shocks for that system to lose its capacity to sustain a certain regime.

A major focus of urban resilience thinking is the role of urban green spaces in producing local ecosystem services, such as air purification, rainwater drainage, sewage treatment and food provision, alongside recreational and social benefits (Barthel et al., 2010; Ernstson et al., 2010b).

However, green space planning in many cities has been negatively affected by institutional failures to acknowledge the mutual benefits that ecosystem services supply to both ecological and social systems (James et al., 2009; Jansson and Polasky, 2010; Sandström et al., 2006). As a result, the concept of urban green space is often treated one-dimensionally — that it is something *nice* to have instead of providing critical ecological and social functions (Sandström et al., 2006; Van der Ryn & Cowan in Walmsley, 2006). Although there are few exceptions, such as the Brazilian government's success with en-mass green infrastructure investments in reforesting the Tijuk Massif National, the treatment of green assets as an integral part of the infrastructure networks that maintain city functioning remains rare (Da Cunha et al., 2001).

In African contexts, this misperception is particularly perverse since what are seen as purely socio-economic issues – such as poverty and job creation – receive primary attention in social or activist dialogues and planning agendas, which overlook the broader socio-economic opportunities of resilient ecosystems. Similarly, in South Africa, ecological issues receive low priority in relation to social issues, which are often perceived as more pressing on political agendas while conservation is perceived as a luxury, limited to protected areas (Turpie et al., 2008).

Without aligning ecological and economic goals, many pro-poor development arguments neglect the essential role that local ecosystem services can play in wider development (Sattherthwaite, 2008; Swilling, 2007). The isolated pockets of "green" development that consequently exist in many growing cities in Southern Africa represent the political and budgetary precedence given to certain urban services (Beall et al., 2000; Bond, 2007; Von Maltitz et al., 2003).

Green infrastructure planning targets these instances where planning knowledge about the linkage between 'traditional' urban services and ecological processes is either rudimentary or inconsistently applied (Ernstson et al., 2010b; Kremen and Ostfeld, 2005; Palmer et al., 2004; Vanderberg, 2002). In doing so, green infrastructure addresses the social and governance processes needed to ensure effective on-the-ground management of ecosystem services by elevating urban green spaces in mainstream planning (Cowling et al., 2008).

In addition to formally planning green space as networked infrastructure, a green infrastructure framework means acknowledging informal nodes of ecological intelligence. Here, we draw on Barthel et al.'s (2010) notion of social–ecological memory, as the "memory of groups that engage in ecosystem management" to highlight the informal cultures of greening retained and practised in society. These include commercial activities, gardening clubs, horticultural supply chains and wider value chains that develop around green space that constitute important sources of ecological investment to be built into planning processes (Schäffler, 2010).

Green infrastructure therefore encompasses formal ecosystem management and networks of green consciousness that have developed over time. On the one hand, green space planning deficiencies are opportunities for retrofitting our knowledge infrastructure, planning and budgeting to incorporate ecological criteria.

In addition, informal green practices constitute significant reservoirs of ecological knowledge. These citizen engagements create infrastructure regimes that are *interactive* to sustain green systems whilst embedding in cities ecological culture and heritage. This implies investing in long term societal relationships with ecological networks, without which ecosystems will fail to flourish amidst current pressures induced by cities.

2.2. Implementing Resilient Infrastructure

The efficiency of 'grey, human-made physical, infrastructure such as roads, drainage systems and utilities (Yeang, 2008), has become a primary issue for the sustainability of our cities. A rapidly expanding urban infrastructure transition scholarship argues for a reassessment of the way we use resources and infrastructure to maintain more sustainable metabolic flows in cities through the reworking of inter alia, mobility systems, energy networks, water and sanitation supplies, and waste systems (Brunner, 2007; Camaren and Swilling, 2011; Hodson and Marvin, 2010).

The prospects for urban infrastructure transitions are particularly challenging in cities still trying to meet the infrastructure needs of all their residents. One of the key priorities in post-Apartheid South Africa has been investment in urban infrastructure as a key strategic economic and social development policy (Richter et al., 2009; Swilling, 2007). Indeed, social commentators on the state of urban services in South Africa call for the "conscious expansion", "improvement" and "renewal" of infrastructure in cities to enhance access to bulk services, such as housing, water, sanitation, energy and roads, to previously disadvantaged communities (Borraine et al., 2006; Charlton, 2010; Parnell and Robinson, 2006).

In addition, the infrastructure networks under pressure to provide ever-more services for growing urban populations are often the municipal systems of potable water, waste reticulation, wastewater systems and storm-water management. The extent to which municipal infrastructure, both physically and in terms of planning, either erodes or supports resilience is therefore an important consideration in planning for rapidly expanding cities.

In the discussion on infrastructure transitions, an important, but often neglected consideration is how green infrastructure can function as an augmentation, or even an alternative, to existing built infrastructure, dramatically improving cost efficiency and effectiveness in over-stressed systems. For example, green spaces can act as effective storm-water attenuation systems, moderating, or even removing, the need to build large new pipe and channel systems that try to transport storm-water out of the city.

We propose that decisions about implementing resilient urban infrastructure may therefore greatly benefit from a green infrastructure approach that designs cities for the resilient provision of ecosystem services (Kremen, 2005). Including ecological systems as infrastructure service providers may also lessen the reliance on the often irreversible, costly investments in technical connections, and their associated water and embodied energy requirements (Herder et al., 2011; Kremen, 2005). Due to these system-wide benefits, the strategic placement of green infrastructure in urban planning can assist in creating more flexible urban infrastructure, capable of adapting to change, in contrast to fixed grey infrastructure, which essentially remains dormant unless its specific service is required (Egyedi and Spirco, 2011).

3. Case Study Description

Our analysis is based on a case study of Johannesburg, South Africa. Johannesburg's population is estimated at close to 3.8 million, which is a 16.4% change from the 3.2 million in 2001 (StatsSA, 2010). Johannesburg also agglomerates more than one-third of the population in the Gauteng City-Region, which with a population of over 11 million, is one of the fastest growing city-regions in South Africa, absorbing the highest numbers of domestic and international migrants (OECD, 2011) (Fig. 1).

Partly as a result of its apartheid past, and partly due to urbanisation pressures, Johannesburg is faced with a host of challenges including unequal access to shelter, services and decent neighbourhoods. However, Johannesburg is also home to an extraordinary ecological asset, the world's largest urban forest, which, according to the City of Johannesburg, is said to have grown to 10 million trees (CoJ SOER, 2008).

Johannesburg's urban forest is a significant ecological feature that needs to be understood as a product of the city's intersecting industrial and ecological histories. A tree-planting boom began in the late 19th century as an attempt to both settle the dust, and cleanse the air, as a result of intense mining activity during the Gold Rush, and to supply poles to support mine shafts and excavations (Turton et al., 2006). Quick-growing species such as Eucalyptus, Black Wattle and Jacaranda, and varieties with which the colonials were familiar such as London Planes, Oaks and Pepper trees, were introduced during the massive tree-planting scheme (Turton et al., 2006). Unlike the indigenous forests found elsewhere in the world, the planting of non-indigenous, water-intensive trees during Johannesburg's colonial beginnings can therefore explain the incongruency of a forest in natural grassland. The development that accompanied the expanding gold rush town, also resulted in a proliferation, albeit an unequal one, of greenbelts, adjoined by public and private gardens, and parks throughout the city, as revealed by the suburbs of "Forest Town, Parkview and Park Town" (Turton et al., 2006):

> "From the air, the pleasing bright green quilt of well-watered English-style gardens and thick alien trees that shade traditionally white – now slightly desegregated – suburbs, is pocked with ubiquitous sky-blue swimming pools." (Bond, 2007: 9).

Over the last century, the city's trees and associated green spaces have become significant in terms of their scale and geographic reach.

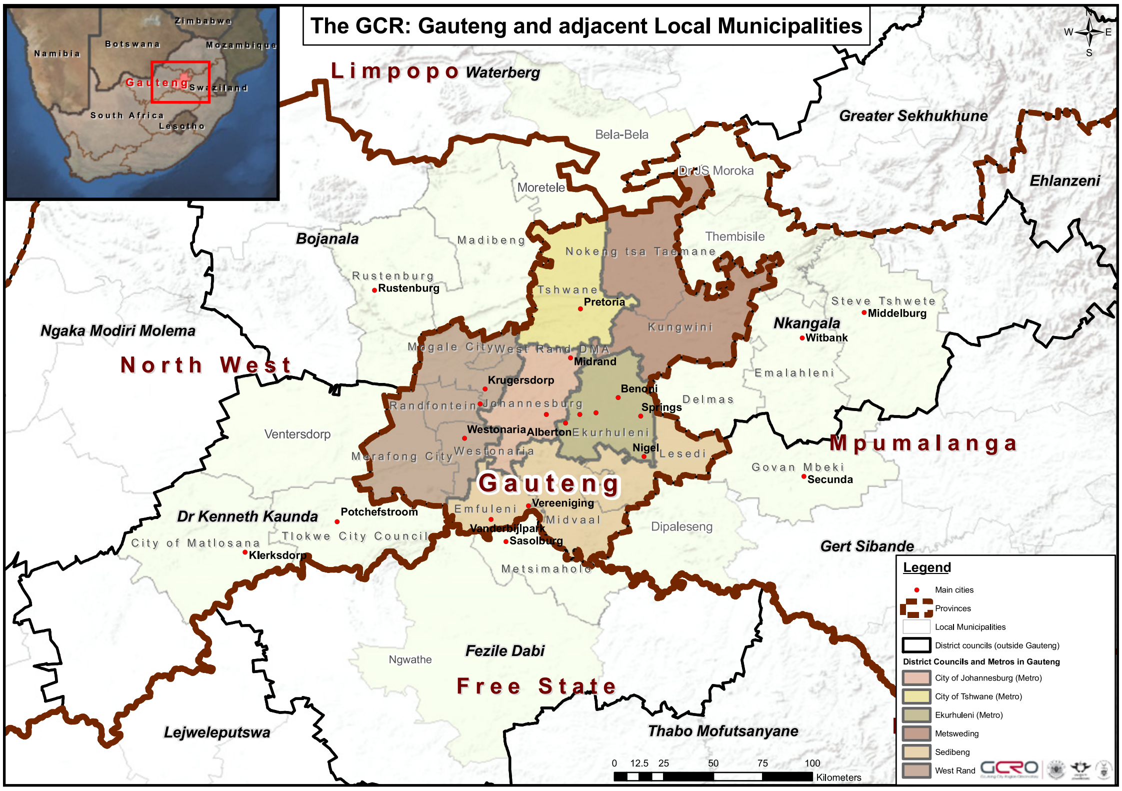

Fig. 1. The Gauteng City-Region and surrounding local municipalities.

Of Johannesburg's 164458 ha, a total of 16.1% is covered by trees, both non-indigenous, imported, forest and residual indigenous forest. Adjoined by green open spaces, Johannesburg's trees form a system of soft, ecological spaces to represent something unique in an otherwise pressurised urban environment, and to show the complex and contradictory nature of urban form.

Johannesburg's urban forest is not without criticism. For example, the dual occurrence of the city's water quality challenges and the largely introduced urban forest is one of the contradictions of Johannesburg's landscape. The urban forest has been criticised for inducing hydrological pressures due to its construction in naturally occurring grassland. This is particularly relevant in the context of South Africa's highly successful Working for Water Programme, a natural resource programme based on poverty relief and public works expenditure, that has addressed both ecosystem service delivery and poverty through the clearing of alien species such as Eucalyptus (Turpie et al., 2008).[2] Yet, in the context of Johannesburg's wider infrastructural challenges, the city's trees and ecological networks provide a set of ecosystem services that uniquely showcase the potential of green infrastructure. Although primary research is yet to be conducted on the full value of the city's forest in addressing infrastructural challenges, a number of obvious contributions can be highlighted.

First, trees may be of benefit in addressing a recently recognised ecological crisis, namely the likely decanting of acid mine water from Johannesburg's old mines into sewer systems, waste water treatment works and natural systems, contaminating shallow groundwater and flooding underground infrastructure (McCarthy, 2010). Acid mine drainage (or AMD) occurs when polluted water from dormant mines reacts with mine strata, waste and oxygen to become highly acidic, with heavy concentrations of salts and heavy metals, rendering water unusable without intensive and costly treatment (IMCAMD, 2010; McCarthy, 2010). This water is rapidly rising through old mine shafts to the surface, and is projected to decant at the surface within a few years. Certain tree species and shrubs are tolerant to toxic conditions, with the ability to immobilise or render pollutants harmless to act as pollutant 'sinks' (Weiersbye, 2007a). These functions are broadly known as phytoremediation, which is the use of plants, algae, soil microorganisms and non-living biomass to improve the quality of a substrate (Glick in Weiersbye, 2007b).

Second, trees, vegetated areas and other ecological assets naturally regulate water flow and storm-water runoff through intercepting and reducing storm-water runoff over impervious surfaces (Xiao in Kirnbauer et al., 2009). This is a critical function in Johannesburg where more intense Highveld thunderstorms and the blanketing of natural drainage systems with hard surfaces are causing increasingly hazardous flash flooding. Trees with a strong vertical anchorage may help to reduce the velocity of fast flowing storm water, thereby enhancing resilience to erosion damage (Neary et al., 2005).

Third, green assets and vegetation in cities in general provide important air-filtering functions in the context of airborne pollution. Through removing air pollutants – Johannesburg's initial rationale for constructing the forest during the gold-mining boom – trees significantly improve air quality (McPherson et al., 1997). Trees also help regulate cities' microclimates, via buffering wind speed, retaining of heat in winter and, in summer, through intercepting solar radiation to cooling urban areas (McPherson et al., 1997). These latter services can mitigate against urban heat island effect in light of the growing number of hard, and heat-absorbing, surfaces in cities.

Fourth, in many cities, physical disconnects have been created between humans and nature, and people are often socially and mentally alienated from life-sustaining ecosystem services (Barthel, 2004; Barthel et al., 2010; Colding and Barthel, 2013-this issue). Reconnections to nature can provide both recreational and deep psychological benefits to address inter alia, youth violence, disaffected social groups and psycho-cultural damage inherited from unequal

[2] While this is not the focus of this paper, future research is required on the future of Johannesburg's largely exotic forested areas and green spaces in light of South Africa's Working for Water Programme which aims to eradicate alien species that critically affect the country's water supplies (see Turpie et al., 2008).

political legacies. Johannesburg's urban forest is often said to contribute a sense of calm and 'quality of life' to an otherwise very frenetic business city. From a cultural point of view, in Southern Africa communities often rely on a deep store of traditional medicinal wisdom and alternative healing practices for their sense of identity and social equilibrium (Geldenhuys, 2007; Kroll, 2010; Schäffler, 2010). Access to natural resources, including indigenous trees in the urban forest, supports traditional healers reliant on age-old ethno-botanical practices such as bark harvesting.

While it is clear that Johannesburg's urban forest is important, there is one fundamental challenge that characterises it. There is a highly unequal distribution in the extent of tree cover and maintained green spaces between the north and south of the city, as graphically illustrated in Fig. 2 below. The forest covers approximately 24.2% of the total area of Johannesburg's historically wealthy northern suburbs, while tree coverage in the poorer southern quadrant is approximately 6.7%.

This uneven distribution is almost universally taken as a physical manifestation of unequal access to services across the city, and has galvanised an active environmental justice dialogue concerned with redressing Johannesburg's ecological disparities. Such disparities are indeed a reflection of wider infrastructure discrepancies, and improved access to green assets should be promoted in the same way as engineered, 'bulk' services. Accordingly, Johannesburg's ecological features should be regarded as units of analysis in their own right, in terms of the services they provide, equated to, prioritised and expanded, in the same vein as the services of hard-infrastructure.

While the environmental justice perspective has indeed led to a massive investment in the expansion of green infrastructure, including a greening programme that saw 200 000 trees planted in the run-up to the World Cup, we argue that this programme has been done hastily, where speed of roll-out to address a historical backlog has been the driving imperative rather than the long-term sustainability of greening projects. Our hypothesis is that an environmental justice perspective, which neglects ecological assets as infrastructure, and overlooks private citizen greening investments, fails to ensure that the wider ecosystem services and economic benefits of the urban forest are taken into account, with negative implications for how the extension and maintenance of this critical green asset are planned.

We have tested this hypothesis in a two-step research process. First, using quantitative methods, we have tried to establish what it would take to properly value the urban forest from an ecosystem services perspective. Second, using qualitative methods, we have tried to determine whether this kind of valuation approach is in any way present within the City of Johannesburg's planning, and if not what are the consequences of this failure to properly value ecosystem services.

4. Methodology

The methodology used in this research is both quantitative and qualitative, based on preliminary investigations conducted by Schäffler (2010) during 2009 and 2010, which sought to value the state of Johannesburg's green infrastructure and the understanding of this value by actors in the city. The quantitative valuation methodology aimed to demonstrate that it is feasible to value two aspects of the ecosystem services provided by Johannesburg's urban forest, first its carbon capture/climate regulation capacity, and second its potential employment and economic contribution. The qualitative methodology was an analysis of planning around green infrastructure to establish whether Johannesburg's ecosystem services have been formally incorporated into city-planning processes.

A mixture of methods was utilised for the two methodologies, including: secondary data analysis, geographic information systems (GIS) mapping, semi-structured interviews, pilot case examples, collection of primary data and empirical observations in sourcing data.

In terms of the quantitative methodology, the primary motivation for using the chosen approach is to indicate the usefulness of total economic valuation for assessing the economic value of green infrastructure, and to contribute to the international applications of this growing area of research (Vandermeulen et al., 2011). Market-based valuation, such as carbon pricing, and employment and supply-chain contributions are seen as useful for signifying the public investment and monetary case of not investing in green infrastructure industries, and thus serve as useful for budget comparisons for municipalities. The limitation of this approach, including various assumptions due to the paucity of primary data, is in reducing ecosystem services to a set of figures, removed from the political economic and decision-making choices that sculpt the way green space is managed and perceived. As such, the paper extends market-based valuation to include surveys of how green space is understood, planned and budgeted for, and the implications of an institutional hesitance to adjust to integrated green infrastructure planning.

While the robustness of the quantitative results would be enhanced by the availability of city-scale primary data on ecosystem services, the results given are seen as valuable proxies for future work on total economic valuation. Together with capacity and time constraints, it is also for this reason that a select set of services are the focus of the quantitative study and in-turn, which prompted an investigation into why planning and research dialogues remain relatively mute on the topic of how our urban green space networks feed into wider development processes.

4.1. Quantitative Methodology

Our approach to the quantitative valuation was inspired by the *Methodology to value the natural and environmental resources of the City of Cape Town* (de Wit et al., 2009), which includes a number of components to value the total contribution of ecosystem goods and services (EGS).

Central to this methodology is the idea of total economic as a framework to "value both market and non-market benefits, as well as values derived from future use, along with values totally unrelated to future consumption" (de Wit et al., 2009). Table 1 shows the full basket of ecosystem services that could be valued in Johannesburg using this framework, and the appropriate valuation techniques for each set of ecosystem services. In our study, only selected regulating and cultural ecosystem services were valued, as indicated by an * in Table 1.

4.1.1. Valuation of Regulating Services: Estimating the Carbon Stock of Johannesburg's Urban Forest

The valuation technique for climate regulation broadly followed a standard carbon stock methodology using a $50 \times 50\ m^2$ pilot study site representative of an urban tree stand that could be extrapolated to city-scale. The methodology calculated tree diameter at breast height, stem lengths and the percentage branch volume of total tree volume. The total carbon stock of Johannesburg was correlated to the market-related carbon prices at the time of this study.

4.1.2. Valuation of Cultural Services: Employment and Economic Contribution of Johannesburg's Green Supply Chain

The methodology for valuing employment contributions of the urban forest estimated the number of households in a low-density suburb in Johannesburg likely to employ gardeners or garden services. Low-density residential areas are assumed to include some form of 'green space' that requires maintenance for its continued existence. This is based on evidence from the City's Spatial Development Framework (CoJ, 2007), that residential dwellings vary from 10 du/ha in golf, equestrian or country estates to 40–70 du/ha in townhouse and cluster developments. Based on the number households

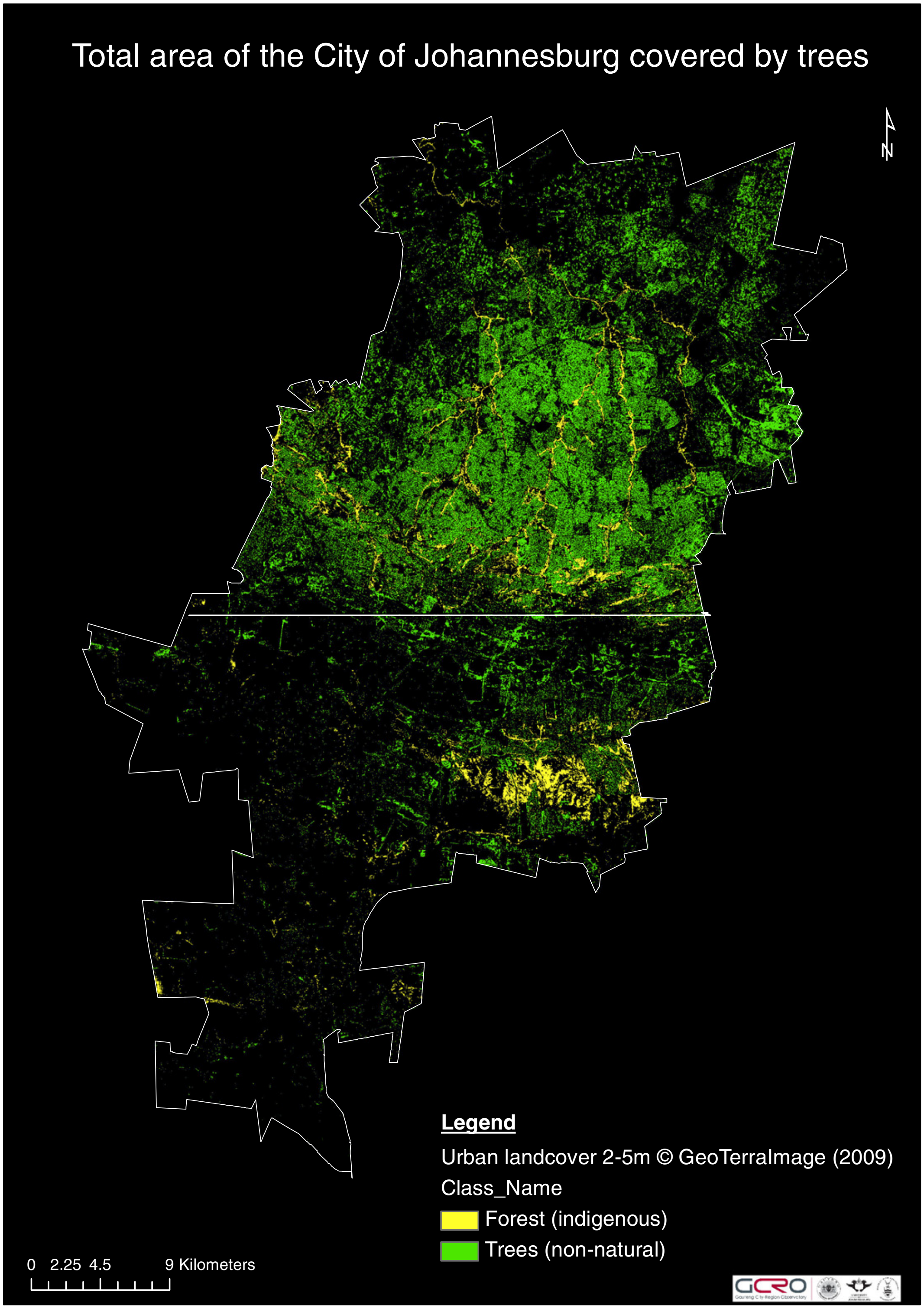

Fig. 2. Total area of the City of Johannesburg covered by trees.

estimated to employ either a gardener or garden services, the approximate garden wage and garden service fees per area was calculated.[3]

Two approaches were used to estimate the contribution of Johannesburg's green assets to industry and economic enhancement. The first used a midpoint calculation of the total turnover range of the South African Nursery Association (SANA), using Johannesburg–Gauteng members, as an indicative worth of the green industry.

The second used data from a commercially generated dataset, Afrigis Bizcount, which spatially maps companies and attributes to them business type classifications based on the standard industrial classification (SIC) coding system (Afrigis, 2010). This system provides turnover figures for each company in a specific classification, the sum of which can be taken as a representative value of all businesses in the group. We calculated the total turnover of all businesses

[3] While the study focuses on investments in garden services and garden employment, residents' own labour in gardening constitutes another source of value, to be assessed in terms of the recreational, social and personal value for people.

Table 1
Basket of ecosystem services matched to valuation techniques.
Adapted from de Wit et al. (2009).

	Ecosystem services	Valuation techniques
Regulation	Water flow regulation (storm-water and runoff regulation)	Replacement costs, preventative costs, disaster management costs and costs of ecosystem failure
	Natural hazard and disaster regulation (floods, etc.)	Substitute costs
	Water purification	Healthcare costs
	Climate regulation (pollutant and carbon neutrality at	Productivity costs
	both micro and macro scales, heat island effect)*	Carbon price
		Economic attractiveness
Cultural	Aesthetic, mental and psychological values	Hedonic pricing and choice value experiments
	Recreation, sport and religious use	Employment and revenue of green supply chain and other revenue-generating greening initiatives
	Job and employment creation*	Economic attractiveness
	Economic and industry enhancement	
	Education and skills development	
	Awareness raising	
	Livelihood enhancement	
	Sparking new industries	
Provisioning	Food provision and food security	Substitute costs/costs of alternatives
	Ornamental services	Hedonic pricing and choice value experiments
	Bark harvesting	
Supporting	Soil formation	Not valued separately, according to methodology
	Photosynthesis	
	Natural composting and nutrient cycling	
	Biodiversity and habitats (broader ecosystem support)	
	Nursing and recovery of indigenous vegetation	

in Gauteng categorised under *Growing of Vegetables, Horticultural Specialties and Nursery Products*.

4.2. Qualitative Methodology

Given the basket of ecosystem services provided by Johannesburg's forest and green systems, the qualitative analysis of planning around green infrastructure is used to assess whether Johannesburg has in any way integrated green infrastructure in service delivery objectives. A series of semi-structured interviews was held with a range of stakeholders directly and indirectly connected to Johannesburg green space system and supply chain. Interviewees included representatives from Johannesburg City Parks (JCP), the South African Landscaping Institute (SALI), the South African Nursery Association (SANA) and the South African Green Industries Council (SAGIC).

5. Results

5.1. Value of Selected Ecosystem Services in Johannesburg

5.1.1. Carbon Stock Estimations of the Urban Forest

On the basis of the workings illustrated in Table 2, we calculated the carbon storage capacity of a representative patch of the urban forest in Emmarentia, a suburb in northern Johannesburg.[4] We found that a $50 \times 50m^2$ woodland area stores an estimated 32.2 metric tonnes of carbon per hectare. This is the approximate amount of metric tonnes of carbon stored in the timber biomass of 39 trees with an average height of 10 m and combined average volume of 64.4 metric tonnes per hectare. Extrapolated to city-level, this translates into a total carbon stock of 5.3 million metric tonnes in the forest, which is valued at € 82 269 015 (USD 64 154 910)[5] using a market related carbon price of € 15.42 (USD 12.10) per tonne. This is the fixed stock value of carbon that has accumulated in the forest over time, otherwise known as the growing stock. If primary data was available on the annual growth rates of the trees, the carbon sequestered over time through the forest per annum could have been calculated.

Table 2
Estimating the carbon stock of Johannesburg's urban forest.
Adapted from Geldenhuys & Berliner (2010).

Stage	Description
	Methodology to estimating the carbon stock of Johannesburg's urban forest
1.	Choose a 50 × 50m area in within the City of Johannesburg's municipal boundaries with a mixture of trees and open spaces to be representative of urban tree distribution
2.	Calculate the diameter at breast height (DBH in cm)
3.	Calculate the stem length to main branches (m)
4.	Estimate the percentage (%) of the branch volume as a proportion of the total tree volume = B (e.g. 70% = 0.7)
5.	Calculate the Basel Area = $\pi * DBH * DBH/40\,000$
6.	Calculate the stem volume = BA * stem length * 0.7
7.	Calculate the total tree volume = Stem volume / (1 − B)
8.	Calculate biomass = tree volume * 0.7
9.	Calculate volume per ha = biomass / 0.25 (metric tonnes per ha)
10.	Calculate biomass per ha = volume per ha * 0.7
11.	Calculate carbon stock = biomass per ha * 0.5 (metric tonnes per ha)
12.	Calculate carbon stock of entire CoJ area = carbon stock per ha * total CoJ ha (164 458 ha)

5.1.2. Economic Contribution of the Green Supply Chain

Table 3 shows an estimated value of the value of garden employment in Johannesburg.

Based on a midpoint calculation of total turnover for SANA's Johannesburg–Gauteng membership, a total of 241 firms, the total annual income for firms in the nursery industry is USD 92 746 683.5 (Table 4). AgriGIS Bizhub figures show that 71 Gauteng businesses in the category *Growing of Vegetables, Horticultural Specialties and Nursery Products*, have total annual turnover of USD 524 999 955 (ZAR 69 999 994).[6]

Although these calculations are speculative, and differ in terms of the annual turnover represented by a given number of firms, they are indicative of the significant worth of Johannesburg's green industry, when compared for example to the annual budget of the City of Johannesburg agency responsible for the urban forest, as explained below (CoJ JCP, 2010a, 2010b, 2010c).

[4] This sample study of biomass stock for a select group of similar trees cannot equate to the biomass stock of the entire city, but is used to estimate carbon storage potential in such an environment. A key task for future research is to calculate carbon storage for various types of vegetation and tree cover combinations, to account for different carbon capture capacities.

[5] Exchange rate used was 1 EURO = USD 0.785.

[6] Exchange rate used was 1 USD = ZAR 7.5.

Table 3
Estimating the value of garden employment.

Stage	Description
1.	Chosen low-density residential area: Greenside (StatsSA, 2001a)
2.	Greenside has 1483 du/ha (StatsSA, 2001b)
3.	If 60% of Greenside households use garden employees, approximately 889 households employ either a gardener or a garden service
4.	If gardeners are employed at an average wage of \$ 16 per day based on the recommendations of a local landscaping company: a) 889∗16 (wage per day) = \$ 14224 b) 14224∗8 (hours per day) − \$ 113792 c) 113792∗245 (days per year) = \$ 27879040 (total annual wage of gardeners per area as calculated above)
5.	If garden service companies are used at an average fee of \$ 240 per month based on the quotes of local garden services: a) 889∗240 (monthly garden service fee) = \$ 215760 b) 215760∗12 = \$ 2589120 (total annual revenue of garden service company as calculated above)

5.2. Green Space Planning and Knowledge in Johannesburg

5.2.1. Formal Governance Processes

Formal green space management is the mandate of the city's under-resourced official conservation and greening agent, Johannesburg City Parks (JCP). JCP is a municipal owned entity that manages a number of ecological assets such as parks, cemeteries, street verges, nature reserves and street trees (CoJ JCP, 2008/9). JCP is formally designated as a section-21 company in South Africa, which means its existence is non-profit, with the mandate to provide and manage designated green spaces for and on behalf of the City of Johannesburg (CoJ JCP, 2008/9).

Through a series of interviews with City Parks officials in 2010, we found that JCP's GIS database was incomplete, lacking key data for public open spaces and ecological networks. We probed in particular around the integrity of data on Johannesburg's urban forest, and found inconsistent and unreliable information.

A figure of between 1.3 and 1.6 million street trees, and 2.4 million trees in public parks, cemeteries, nature reserves and conservation areas, was published in JCP's 2009 reports (CoJ JCP, 2008/9). In interviews, officials at JCP suggested that there are 6 million trees – out of a widely publicised figure of 10 million trees in Johannesburg's urban forest – that are publicly managed (CoJ JCP, 2010a, 2010b, 2010c). However, the last official inventory conducted by JCP – an official city-wide tree count conducted in 2010 – failed to verify these figures. The street tree census managed to record only 240000 trees (CoJ JCP, 2010a, 2010b, 2010c).

Fig. 3 illustrates the challenge by showing the limited number of trees, generally street trees, captured by JCP. Not only does the count not capture all street trees visible on the backdrop satellite image, it is clear that the census failed to account for the majority of trees and green spaces that exist in private gardens.

Data deficiencies aside, there has been an extremely positive roll out of greening projects and ecological assets rehabilitation programmes that have gained momentum in Johannesburg over the last few years, and in particularly in the build up to the 2010 Soccer World Cup. However, our qualitative research indicates that these greening projects receive attention largely as short-term, high-pressure commitments to reduce "ecological disparity" (CoJ JCP, 2008), raising questions about the commitment to sustain green assets over the long term.

Table 4
SANA datasets showing total range of economic contribution for the Johannesburg–Gauteng members (SANA, 2010).

SANA datasets (2010/2011)					
Membership category	USD range		USD midpoint	Number per category	USD total annual income
Category 1	0	86666.7	43333.3	59	2556666.7
Category 2	86666.8	266666.7	176666.7	99	17490006.6
Category 3	266666.8	866666.7	566666.7	48	27200003.2
Category 4	866666.8	433333.4	1300000.3	35	45500007.0
Total					92746683.5

For instance, the bulk of Greening Soweto, declared a 2010 World Cup legacy project, took place in winter, when the Highveld frosts hit the hardest, and particularly in Soweto, resulting in many of the trees not surviving the cold (CoJ JCP unnamed sources, 2010a, 2010b, 2010c). An ex-city official, who worked on city-wide strategic plans during the mid- to late-2000s, gives the following insight into this greening programme:

> "Over 2005 and 2006, officials from across the city sat down to decide on key programmes of action for the 2006–2011 integrated development plan (IDP). One of the key programmes discussed was that the City would plant 1000000 trees over five years. Just before the IDP was approved it was suddenly decided that this was too ambitious and the number was cut to 200000. Then it became, "plant 200000 trees in Soweto as a township greening programme in time for the FIFA World Cup". The whole logic of the project became to plant as many trees as possible in the shortest timeframe so as to be appearing to address the disparity between so-called leafy green suburbs and dusty townships. This wasn't necessarily bad, but there were clearly missed opportunities in the rush for a big rollout of trees in Soweto. For example, it was argued in one Budget Panel meeting that the City might explore incentives to Soweto homeowners to take care of trees planted by the City in their yards or outside their properties — incentives like a one-off rebate on property tax on condition that the tree was still alive and well after two years. It was also argued that the City could use the massive tree planting exercise as a way to simulate micro-businesses or co-operatives of community members to grow, plant and maintain trees on a 5-year commission, instead of the City just planting trees donated by corporates or grown in City-owned nurseries. These ideas weren't pursued in the rush to put trees in the ground."

In 2010 interviews, officials at Johannesburg City Parks conceded that they had not done any of the sorts of calculations illustrated above to establish the carbon storage potential of the urban forest. Nor did they perceive any need to undertake such quantitative assessments.

Through follow-up interviews in 2011 with officials in the City of Johannesburg's Environment Department, as well as the Johannesburg Roads Agency, the entity responsible for storm-water management, we established that there was little incentive within the frameworks of broader infrastructure planning to invest in ecological assets as green infrastructure. As far as storm-water management and sewage treatment is concerned, investments are mainly in traditional 'grey' systems, such as enhanced motorway capacity, and upgrading of bulk wastewater systems. While officials are aware of the possibilities of using green infrastructure in enhancing storm-water management, they are clear that there are no current or immanent programmes to invest in green assets for this purpose, even on a pilot basis.

Interviews indicate that the greening of Johannesburg also takes place without consideration of the employment and wider economic benefits of coherently planned green infrastructure. Although the employment and turnover calculations, shown in Table 4 are speculative, they are suggestive of the value of consciously planned efforts to promote the expansion of green supply chains. An analysis of the 2010/2011 Johannesburg City Parks budget shows that ZAR 26.5 million (USD 3.5 million)[7] has been allocated to continuing the Johannesburg's tree-planting programme. This is minute compared to the almost ZAR

[7] Exchange rate used was 1 USD = ZAR 7.5.

Fig. 3. City of Johannesburg tree land cover capture.

700 million (USD 93.3 million) turnover of an established green industry indicated by our provisional analysis.

Our qualitative research into official planning processes around Johannesburg's primary ecological assets – its urban forest – concludes that while there is certainly an effort to expand the asset, there is no coherent approach to planning for it as green infrastructure. The asset tends to be perceived in the traditional sense, as a project of city beautification, where the primary concern is the disparity between how disadvantaged areas look relative to the leafier green suburbs in the northern part of Johannesburg. There is little if any sense of the forest as a provider of key urban services. Although the 2010 Annual Report from JCP does recommend that the entity should try for a 95% survival rate of newly planted species (CoJ JCP, 2010a, 2010b, 2010c), it is unclear how this is to be achieved as there are no detailed maintenance interventions or budgetary provisions for this goal. Without seeing greening as an economic driver, and planned as such, government structured greening programmes have also missed the opportunity for new industries to develop alongside ecological assets in projects to extend the urban forest. Traversing this are the significant knowledge and data deficiencies in terms of the real size and functioning of an estimated 10 million trees.

6. Discussion

6.1. The Need for Innovations in Municipal Accounting Systems

Our quantitative and qualitative analysis of the extent to which the urban forest has been adequately valued, leads us to the conclusion that it is imperative to redesign cities' budgeting, accounting and municipal asset management processes to better accommodate green infrastructure. Innovations are required to bring clarity on the opportunity costs of not investing in ecosystem services, and beyond that on the scale and location of required ecological investments, both in terms of the capital costs of developing green infrastructure, and the operating costs of maintaining it (Choumert and Salanié, 2008; Kremen and Ostfeld, 2005).

Importantly, mainstreaming ecosystem services in municipal accounting systems can uncover how services appreciate in value, in terms of their stock, quality and overall health. This brings a new perspective on municipal accounting systems and asset registers in which infrastructure assets traditionally depreciate over time. In standard municipal accounting practice, time-based depreciation rates are applied to fixed infrastructure assets (SPAID, 2010). There is currently no way of formally valuing the appreciation of ecological assets, such as tree growth or ecological productivity.

On the contrary, through investing in the productivity of ecosystems, ecological assets can appreciate if their associated ecosystem services are valued in municipal asset registers. We have shown, through selected preliminary experiments, the potential of such a valuation approach. This however requires a transformation in municipal budget paradigms on two accounts. First, monetary values must be given to green infrastructure assets, and second, accounting systems need a thorough conversion from an approach which inherently assumes depreciating value, alongside increased maintenance costs of traditional grey infrastructure networks, to ones which can formally register how an asset that grows naturally by itself, becomes innately more valuable over time, with commensurate expansion in the ecosystem service opportunity costs of not investing in it.

Key issues to be resolved are the mechanisms necessary to facilitate this process of conversion. A number of mechanisms could be contemplated, including total economic valuation systems, itemised ecosystem service accounting and in-depth functional inventories for ecological infrastructure (Turner et al., 2003; UNHabitat, 2008). In light of the acute financial strains facing municipalities around the world, the proper categorization of ecosystem services in budgets, accounting systems and asset registers could also conceivably unlock latent revenue streams, rooted in the productivity of ecological assets, as an innovative way of generating revenue for local governments.

We acknowledge that attributing a financial value to ecosystem services is an economistic approach that runs the risk of reducing a complex set of ecosystem services to a single unit of valuation. The approach may also fail to address the underlying power asymmetries that effectively reproduce unequal access to natural resources, especially in a city such as Johannesburg where there is a spatial imbalance in green infrastructure coverage which aligns with the race and class divides of the city (Kosoy and Corbera, 2010). But if judiciously applied, ecosystem valuation may stimulate improved public spending for green infrastructure (Chee, 2004).

6.2. The Need to Recognise Unofficial Cultures of Greening

While it is important to properly account for the value that accrues to a city such as Johannesburg from its ecological assets, it is also critical to understand the social processes that sustain the potential of these assets.

In contrast to the paucity of knowledge within official planning practices, Johannesburg has inherited an economy and culture of greening that forms an overlooked reservoir of ecological investment. This can be derived from the significant proportion of the trees in Johannesburg that are managed privately — approximately 3 to 4 million trees are estimated to grow in private gardens throughout the city's suburbs (CoJ JCP, 2010a, 2010b, 2010c), although of course the number of trees at the private tree and garden level is not statistically proven. Importantly, this private construction of the urban forest has sparked a green industry, including garden services, landscaping business and nurseries, through which jobs, revenue and knowledge are continually re-invested into Johannesburg's major ecological asset (Hoy, 2009). Despite a lacklustre formal effort towards green infrastructure, citizens themselves are creating bottom-up sources of ecological knowledge, which are significant investments beyond municipal planning practices. This is a product of the interactive nature of green infrastructure and offers a way of rethinking citizen engagements with infrastructure systems.

Such supply and knowledge chains not only serve as repositories of 'social–ecological memory', but also are important sources of employment in the current strained economic context. These are important foundations of urban social resilience, and deserve attention amidst Johannesburg's wider unemployment concerns. Approaches to service delivery all too often overlook the possibility that citizens themselves can be co-constructors of their future. Green infrastructure demonstrates the possibility of a service delivery partnership based on co-responsibility of ecological assets and serious engagements with citizen networks.

A key objective for future research is a more detailed understanding of citizen investments in sustaining green infrastructure, such as the economic contribution of horticulture and gardening supply chains. This is crucial from the point of view of official planning, where the value of citizen greening networks may be significantly enhanced, either through financial incentives for community- or household-led tree planting and maintenance, or by building citizen engagements into planning processes to ensure the improved design of green infrastructure. This also holds true in terms of how cultures of, and investments in, greening can provide the spatial support to life-sustaining ecosystem services such as local food provision, as the key connection between urban landscape and function.

7. Conclusion

In addition to reengineering infrastructure networks for resource efficiency, rapidly expanding cities can find sources of resilience in their 'green infrastructure'. This builds on research on cities as social–ecological systems, which presents a compelling case for including green spaces, as sources of ecosystem services, in urban ecosystem management and planning (James et al., 2009).

Inserting the value of ecosystem services provided by green infrastructure into the matrices of traditional infrastructure choices and budget decision-making criteria is critical if we are to have more sustainable cities, especially in Sub-Saharan Africa. The condition for this in turn is detailed ecosystem service valuations and calculations that can help determine the potential of green infrastructure in addressing urban challenges. While ecosystem valuations have been conducted in various Sub-Saharan ecosystems there is a need to move beyond rural assessments, such as carbon storage in the Little Karoo in South Africa, or the effects of urbanisation on ecosystem service delivery elsewhere, to applications that focus on urban ecosystem services and local-scale investigations within urban regions (Bohensky et al., 2004; UNEP-WCMC, 2011). This may suggest a tendency for ecological valuation studies to give preference to data-rich regions, such as the Gariep Basin, as well as those 'distant' communities affected by urban development (Bohensky et al., 2004; MEA, 2005). The implication is often to deflect attention away from prioritising ecosystem services for complex cities such as Johannesburg, its mix of low-density suburbs, interspersed with green corridors and trees, and under-serviced settlements, adjoined by open spaces, and from the task of collecting baseline data for these diverse city spaces.

The study shows that a strategy of incorporating ecosystem valuations into municipal budgets and accounting systems, and related baseline data collection, needs to be coupled with the investments that are already made by citizens and economic supply chains that already interact with and gravitate around green infrastructure. As we have shown, these community networks and green businesses have important implications for intersecting social–ecological and infrastructure challenges that fundamentally affect the resilience of urban regions. A key highlight is that if valued on par with other infrastructure utilities, ecological assets can boost ecosystem service provision, employment creation and economic attractiveness. While this is an important insight within the context of green economies, the contribution of ecosystem services to wider development processes needs to be made explicit for a sound *economic* case of investment in natural assets, and for discussing resilient urban futures in fiscally strained municipal contexts.

The immediate task for cities like Johannesburg is to harness its green infrastructure potential by engaging more closely with the groups that already sustain the city's trees and interspersed green spaces, which are largely untapped infrastructure assets. Importantly, communities and citizen networks could provide information on vegetation species and green spaces, to help close the vast data gap on urban ecosystem services, and the prioritisation, and value, of these in light of water and food pressures. The general implication is for an urban resilience discourse rooted in robust empirical assessments on the nature, composition and distribution of urban green networks. Through understanding the 'state' of our green infrastructure, we can begin questioning what type of ecological and technical infrastructure, and planning, is needed to enhance resilience between people and nature in urban environments.

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