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REPORT

Urban Transitions: On Urban Resilience and Human-Dominated Ecosystems

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Abstract Urbanization is a global multidimensional process paired with increasing uncertainty due to climate change, migration of people, and changes in the capacity to sustain ecosystem services. This article lays a foundation for discussing transitions in urban governance, which enable cities to navigate change, build capacity to withstand shocks, and use experimentation and innovation in face of uncertainty. Using the three concrete case cities—New Orleans, Cape Town, and Phoenix—the article analyzes thresholds and cross-scale interactions, and expands the scale at which urban resilience has been discussed by integrating the idea from geography that cities form part of "system of cities" (i.e., they cannot be seen as single entities). Based on this, the article argues that urban governance need to harness social networks of urban innovation to sustain ecosystem services, while nurturing discourses that situate the city as part of regional ecosystems. The article broadens the discussion on urban resilience while challenging resilience theory when addressing human-dominated ecosystems. Practical examples of harnessing urban innovation are presented, paired with an agenda for research and policy.

Keywords Urban resilience · Ecosystem services · Social–ecological processes · Cross-scale interactions · Urban innovation · New Orleans · Cape Town · Phoenix

INTRODUCTION

Contemporary urbanization is a global multidimensional process, which manifests itself through changes in human population densities and land cover that are so rapid that we lag behind in understanding the process and its consequences. At the same time, we are facing an increasing uncertainty due to climate change, migration of people, and changes in the capacity of ecosystems to generate goods and services. In an urban context, this means that the traditional paradigm of planning for a predictable future is not only insufficient, but it may, in some ways, also be destructive. This article strives to lay a foundation for transitions in urban planning and governance, which enable cities to navigate change, build capacity to withstand shocks, and locate sources of experimentation and innovation in face of uncertainty.

The city can be thought of as an agglomeration of contested spaces that generate a range of urban services, from transport, housing, and medical aid, to jobs and financial markets (Harvey 1996). A presumption in this article is that such services are inextricably linked to ecological processes and the focus lies on such "ecosystem services," i.e., the benefits urban inhabitants and cities derive from ecosystem processes including, e.g., improved water and air quality, storm protection, flood mitigation, sewage treatment, micro climate regulation, and recreation and health values (Daily 1997; Bolund and Hunhammar 1999; Elmqvist et al. 2008). As ecological processes are in turn modified and entangled in social, and therefore political processes (most obviously through competing land-uses), the city comes into view as constituted out of political social–ecological processes (Swyngedouw 2006; Pickett et al. 2008; Grimm et al. 2008). Based on this, a normative strategy for urban governance would be to maintain or even enhance essential ecosystem services and to accomplish this in ways that recognize the spatial distribution of ecosystem services and their relation to social equity. The two-fold proposition of this article is that resilience theory from ecological research can contribute to our thinking on this normative goal, and that cities can help challenge traditional propositions used by resilience theorists when addressing human-dominated ecosystems. Our belief is that a resilience theory for human-dominated ecosystems is critically needed because such ecosystems are spreading across Earth.

In order to facilitate our discussion, we employ three important case studies—New Orleans, Cape Town, and Phoenix—these cities being suitable since they bring forth some of the most challenging issues of contemporary urbanization: climate change and rising sea levels, growing inequity in the access to resources, conflicts over water use between urban growth and agriculture, and the challenges of energy use and urban sprawl. Through pairing insights from our ongoing research in these cities, with ideas from geography and sociology, we will make four arguments that together aims to broaden the theoretical discussion regarding urban resilience:

- First argument will exemplify how urban social–ecological processes often work at different scales and how *cross-scale interactions* can be a key in driving changes in slow variables to push urban systems across thresholds;
- Second argument will utilize findings from geography, which position cities as part of "*systems of cities*" and reconceptualize cross-scale interactions as interdependencies between technical and social networks that tie cities together and sustain flows of energy, matter, and information;
- Third argument will draw upon findings that demonstrate that *cities are extreme innovation hubs*, with important impacts on technology, economy, and social organization;
- Fourth argument will discuss how to *harness urban innovation*, in the context of the politicized environment of the city, so as to make urban governance more sensitive to ecosystem dynamics and proactive in facing interlinked social–ecological uncertainties.

The last argument implies a call to combine systemic and functional understanding of cities (through resilience theory), with cultural critique and political perspectives. We limit our discussion to the quite well-resourced cities in high- and middle income countries.

Resilience theory—in its current form closely linked to complex adaptive systems theory (Levin 1998)—models reality as consisting of identifiable parts that through localized interaction (process) produce stable patterns (structure) across temporal and spatial scales (e.g. Holling 1973; Gunderson and Holling 2002; Berkes et al. 2003; Folke 2006). These patterns could be plants and pollinators that interact to produce landscape patterns, or the extension of a city through car transport generating sprawl. A key thought is that "positive feedbacks," i.e., processes and

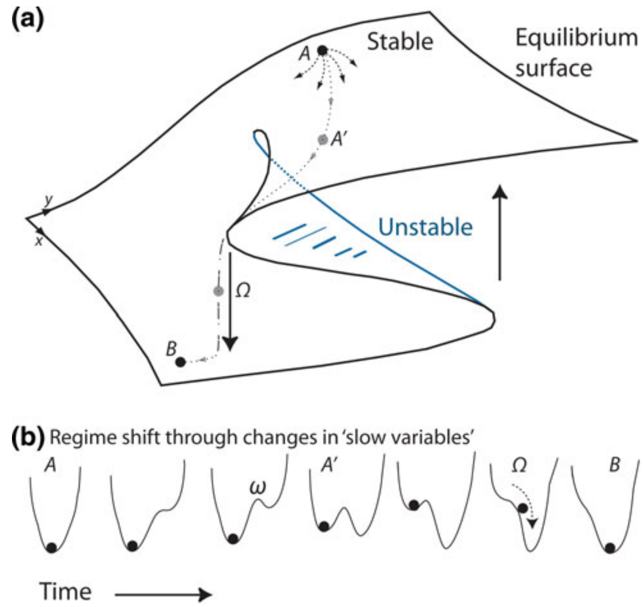

Fig. 1 Regime shifts, slow variables, and thresholds. The figure (**a**) shows a simplified image of how changes in slow variables can produce a regime shift. An example trajectory of a regime shift is followed from *A* to *B*. Even in *A*', there is no great noticeable change in system dynamics, but as the system moves through a threshold at *Ω*, a rapid reorganization into a new stable regime with qualitatively different system dynamics occurs (see Holling 1973; Zeeman 1977; Levin 1998; Gunderson and Holling 2002). It is consequently not necessary for a system to experience a disturbance to "fall into" regime *B*. However, and as illustrated in bottom figure (**b**), as the system looses resilience (lower and lower depth of valley *A*), it takes smaller and smaller disturbances for the system to be "pushed" across the threshold *Ω* (i.e., to be pushed over the middle peak *ω*) so as to fall into state *B*. The combination of changes in slow variables (e.g., sea level rise, duration of dry spells) can thus move the system closer to thresholds, where disturbances (e.g., tsunamis, droughts) can trigger disasters. For coupled social–ecological systems, the set of ecosystem services in *A* can be markedly different from those in *B*

structures that mutually reinforce one another sustain dynamic and path-dependent stability regimes that shape and govern system dynamics (and thus influences localized interaction). Indeed, these processes of self-organization create systems far from equilibrium, characterized by external input and multiple possible outcomes of system dynamics (Levin 1998). Through often unnoticed slow changes in these structuring processes (indicated through changes in "slow variables"), the system can pass thresholds and reorganize—often triggered by a period of rapid change or disturbance—into a new regime in which system dynamics are qualitatively different. This is depicted in Fig. 1 where changes in two slow variables (along the *x* and *y* axes) are seen as "moving" the system on an "equilibrium surface" that is folded upon itself generating inherent thresholds (Zeeman 1977). As the system moves, its current stability regime changes shape (Fig. 1b), demonstrating that as resilience declines, systems are exposed to greater risks, uncertainties, and surprises; it often takes progressively smaller shocks for that system to lose its capacity to sustain a certain regime. Often disturbances and changes in slow variables are influenced by cross-scale interactions and likewise should ecosystem services be seen as emergent from interlinked processes at different scales. Ecosystem services are thus not controllable in themselves, but different regimes uphold distinct sets of ecosystem services, and some ecosystem services could be lost (and others emerge) when a new regime is established (Folke et al. 2004).

From a resilience perspective (Folke et al. 2005), governance can be thought of as purposeful collective action (among state, private, and civil society stakeholders) to either sustain and improve a certain regime, or to trigger a transition of the system to a more preferable regime; these are referred to as adaptive capacity and transformative capacity, respectively. While our shorthand definition of resilience is to sustain a certain dynamic regime, urban governance also needs to build transformative capacity to face uncertainty and change (cf. Berkes et al. 2003).

Several elements of resilience theory are highly relevant to cities (cf. Batty 2008). However, given its origins in ecology, it is not surprising that most resilience scholars have historically been interested in empirical analyses of non-urban areas (e.g., shallow lakes, production forests, and small-scale agriculture, see Berkes and Folke 1998; Gunderson and Holling 2002; Berkes et al. 2003), and have devoted less attention to the specifically human and social elements of human-dominated systems, such as cities. In order to address urban resilience, we propose a distinction between at least two scales that can aid in aligning analysis, governance and urban politics.[1] The first concerns "resilience *in* cities," which operates at the city scale and deals with sustaining local-to-regional ecosystem services. The second is "resilience *of* cities," which instead operates at the scale of a "system of cities," which is a concept from geography meaning a set of cities tied to each other through relations of exchange, trade, migration, or others that sustain the flow of energy, matter and information among the cities (Pumain et al. 1989; Batty 2008). The resilience *in* cities, which has been the main preoccupation of most urban ecologists (Alberti and Marzluff 2004; Pickett et al. 2004; Andersson 2006; Colding 2007), is tightly linked to urban form and land-use patterns on the one hand, and local and spatial ecological processes on the other. This involves stakeholders like urban planners and housing companies, but also housing, squatter and urban social movements, along with those influencing and/or have knowledge about urban ecological processes. The latter group importantly includes, apart from conservation managers, also user groups engaged in local level social–ecological interactions such as urban community gardening, farming, and forestry that simultaneously meet social needs while improving ecosystem function (Stanvliet et al. 2004; Barthel et al. 2005; Borgström et al. 2006; Colding et al. 2006; Andersson et al. 2007; Tidball and Krasny 2007; Krasny and Tidball 2009; Barthel et al. 2010; Ernstson et al. 2010). The second scale, resilience *of* cities, involves a broader category of stakeholders, but particularly those associated not only with technical networks like water, electricity, sewage, waste disposal, and telecommunications, but also with agriculture, mining and other broader interests in society. Along with our four arguments, we will use these scales to broaden the discussion on urban resilience.

FIRST ARGUMENT: SLOW VARIABLES AND THRESHOLDS

Although not in the strict sense specific to resilience theory, an important part in its development has been the idea that slow variables may push systems over a threshold, first developed by René Thom and then elaborated by Christopher Zeeman (Zeeman 1977) (Fig. 1). In this section, we will, therefore, take the city as an example of the ways in which slow variables and thresholds may combine to precipitate irreversible changes.

Urban populations worldwide continue to aggregate in areas that are vulnerable to combinations of slow variables (e.g., sea level rise, periodic flooding, etc.) that can move the system closer to thresholds (situations where "disasters are waiting to happen"), where disturbances (e.g., tsunamis, hurricanes, etc.) can trigger disasters (Fig. 1). As a deltaic city, New Orleans has always been situated in a dynamic landscape, and its recent history—with Hurricane Katrina in 2005 devastating the city leaving 1,500 dead and tens and thousands without homes—therefore provides an important case study to illustrate the interaction between thresholds and changes in slow variables (Fig. 2).

After achieving its peak urban population in the early 1960s, during the 40 years before Hurricane Katrina, New Orleans was experiencing trends in multiple slow variable indicators that, in combination, worked to make the city increasingly vulnerable; rising seas, a compacting deltaic landscape, population decline, suburban sprawl in areas below sea level, coastal wetland loss, economic decline, and low maintenance of levee systems (Campanella et al. 2004; Kates et al. 2006). In terms of most of these indicators—that were well known at the time (Westrum 2006)—New Orleans was heading toward crucial thresholds, but Hurricane Katrina provided a shock to the New

[1] First author acknowledges early discussions with Erik Andersson, SLU, Sweden, on the scales of urban resilience. See also his article, Andersson (2006).

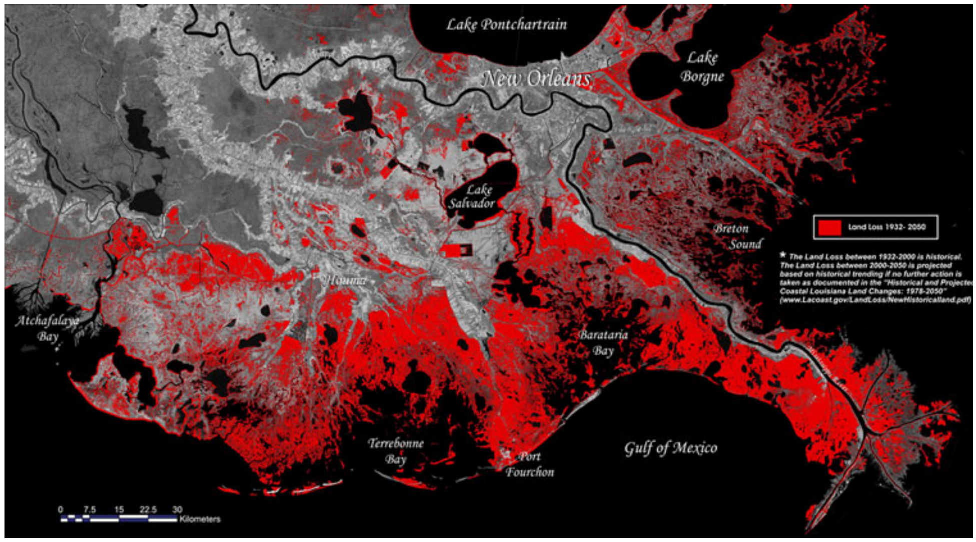

Fig. 2 Loss of land as slow variable in Louisiana. The figure shows the historical and projected loss of deltaic plain land between 1932 and 2050 (in *red*), averaging 65–90 km^2 per year (USGS 2004). According to the US Census Bureau, New Orleans had approximately 310,000 people in 2008, compared to 484,000 before Hurricane Katrina. *Source*: Image courtesy of the US Geological Survey

Orleans urban social–ecological system that pushed the system state half a century into what its future would have been had the hurricane, or a similar shock, not struck the city during that period (Fig. 3). With the spark of academic, private, and civic engagement that the hurricane created, New Orleans provides valuable clues for how urban planning can transition to sustain and build resilience, especially in vulnerable deltaic cities.

How do prevailing gradual environmental trends (e.g., relative sea level rise and coastal wetland loss) and acute threats (e.g., hurricanes and flooding) impact urban and rural coastal carrying capacity in Louisiana? The pre-Katrina trend was already one of dramatic historical wetland losses, since these regions are the vestiges of former Mississippi River delta lobes, and subject to natural compaction and deterioration. Historically, despite compaction, this deltaic habitat had a net gain of land due to the sediment contributions from the Mississippi River Basin, which built these deltas as well as the sediments, sands, silts, and clays that nourished adjacent wetlands through seasonal flooding over the natural levees. However, human interventions that have reduced or eliminated these sediment contributions (e.g., upstream dams and enhanced leveeing/channeling of the Mississippi River) or have resulted in other direct and indirect wetland losses (e.g., oil and gas exploration, wetland conversions to agriculture and other developments, and introduction of invasive nutria species that eat and kill wetland vegetation) have eliminated the ability of these wetlands to maintain their elevations relative to contextual sea level rise, which in turn have increased vulnerability of human settlements and infrastructure to storm surge events.

Fig. 3 Hurricane Katrina as disturbance to an already vulnerable urban system. The photo shows the flooded Lower 9th Ward, New Orleans, Tuesday morning, August 30, 2005. *Source*: Image courtesy of Smiley Pool/The Dallas Morning News

One fundamental change in perspective that resilience theory brings to case studies like this is that, rather than defend against slow changes by means of man-made changes in the landscape, it is less costly and more sustainable to adapt and integrate human settlement to promote restoration of larger-scale biophysical (or "natural") processes (e.g., large-scale freshwater and sediment diversions) and long-term trends that threaten the landscape (e.g., sea level rise). From this viewpoint, one can examine New Orleans' local and regional habitats in terms of the ecosystem services they provide, or could provide, and aid prioritization of interventions so as to generate certain ecosystem services at different scales. Together this leads to a re-conceptualization of the geographical and socio-cultural idea of the city; rather than taking the city as starting point and transforming the physical environment to suit it, a reciprocal relationship can be nurtured, which integrates the city as part of dynamic landscapes and regional ecosystems.

In New Orleans, the multiple changes in a set of slow variables allowed for a sudden shock to create great devastation. Especially, the loss of coastal wetlands in the river delta proved important. In Cape Town, should such a trajectory be in play, we suggest a combination of slow variables including the growth of water consumption (climbing both per capita and through immigration with 80,000 more inhabitants per year), the rate and pattern of land use transformation (including loss of agricultural land, natural habitat, and biodiversity), coupled with deeply embedded social inequity rooted in colonialism and apartheid (Besteman 2008).[2] There are certainly other parameters that could be considered (HIV/AIDS, unemployment, etc.), but we suggest these are indicative for this exploration.

Fresh water for human use is a limiting resource for the growth of Cape Town. Public data indicate that an almost exponential growth of dammed water over the last century and per capita water use has grown from 7 m^3 per inhabitant in early 1900s to 350 m^3 in the 1980s.[3] With little opportunity left for further damming of rivers, plans are considered to mine deep aquifers in the Table Mountain Group, a large mountainous region along the west and south coasts of South Africa. This is a process involving great uncertainties regarding the calculation of recharge rates, and the effects of penetrating deep artesian structures on for instance wetland ecosystems (Xu et al. 2007; WRC 2008; TMG 2008). Although higher water consumption may reflect (unequal) economic growth in manufacturing, agriculture (especially wine industry), and tourism (OECD 2008), it has also led to a deepening of unequal access to water that follows old apartheid era patterns. In parallel, there are indications of slow ecological deterioration on regional river ecosystems and the capacity of estuaries to function as re-production sites for coastal fish (P. de Villiers, pers. comm.), and possibly also impacts on the habitat of "scenic" mammals like penguins that are important for tourism.

In order to further understand the change of slow variables in Cape Town, the quest for urban space linked to oppressive social inequity can be used as a lens. Conditioned by the legacies of racist urban structures, Cape Town has extended fast, occupying 40% more space today than 25 years ago (City of Cape Town 2006). Since Cape Town lies within the Cape Floristic Region, a hotspot of plant biodiversity based on fynbos vegetation, one effect is rapid conversion of fertile farmlands on the one hand, and space for biodiversity on the other, into urban uses. The former vineyards and rich granite-derived soils of Constantia Valley have all but disappeared under the houses, lawns, swimming pools, and golf courses of wealthy suburbs. In parallel, the well-drained, slightly acidic sands of Cape Flats east of the city center, which for decades were used for vegetable farming, have increasingly been utilized for high-density/low-rise and low-cost housing, including informal shack settlements undermining urban food security. In general, wealthy (and mostly white) home-owners have sprawled into attractive mountain and costal areas, while poor black citizens have been concentrated (first by apartheid laws, and then by neo-liberal market constraints) in the wind-swept and flood-prone marginalized areas of Cape Flats, poorly serviced with water, sanitation, education, and public transport (Turok 2000; Besteman 2008).

The apartheid-era-planned township of Khayelitsha illustrates how this oppressive social inequity erodes the capacity to sustain ecosystem services. Here citizens place their shack dwellings on the last remaining strip of coastal dunes, which erodes natural protection to strong prevailing winds while undermining access to recreational space and open air classrooms for learners, and the possibility to collect traditional medicinal herbs (Fig. 4). While the dunes also represent an important fynbos biodiversity system, urban inequity undermines conservation interests and reduces the dunes' socio-economic values; the lack of sanitation infrastructure increases pollution, while urban poverty drives up crime, diminishing the area's recreational and tourism value. Linked to over-consumption of space by wealthy Capetonians, the capacity to sustain ecosystem services in Khayelitsha is eroding.

Taken together, we might witness a convergence of the interlinked factors of higher water consumption, rapid land-use changes, and increasing inequity that could induce shifts in Cape Town's regional and local ecosystems and undermine resilience to future disturbances. These could comprise both global food crisis, but also those of climate change, which is expected to give less overall rainfall in shorter bursts (Midgley et al. 2005), the latter pushing the system to cope with less amount of dammed and controlled fresh water (craved by more inhabitants), and more flooding events (affecting more marginalized people).

In Phoenix, the most apparent candidates for slow variables that structure its dynamics are the low-density urban form along with increasing consumption levels of water, agricultural land, and biodiversity. Phoenix lies in a flat alluvial basin at the confluence of the Salt and Gila

[2] In discussing Cape Town with its previous institutionalized apartheid system, we recognize that racial categories are social constructs that serve certain interests of domination. However, through practices of domination, racial categories nonetheless become real as they constrain or facilitate individuals' access to society's resources.

[3] It needs to be acknowledged that average per capita numbers conceals high inequities. For instance, people classified during apartheid as whites consumed more water than the majority, e.g., through being owners of wineries and being better connected to water infrastructure.

Fig. 4 Inequity as slow variable in Cape Town. Linked to overconsumption of space by high-income citizens, other citizens are pushed to build their shack dwellings in marginal and vulnerable ecosystems, as in these sand dunes in Khayelitsha, Cape Town. With 3.9 million inhabitants, the city grows by 80,000 people per year, mainly due to migrants from rural countryside, and other parts of Africa. City poverty lies at 32% (household income less than 150USD), unemployment at 22%, and there is extreme levels of income inequality (gini coefficient at 0.68). Khayelitsha, with 12% of the population, contributes to just 0.70% of the city's GDP (OECD 2008). Photo by Henrik Ernstson, 2008

Fig. 5 Urban sprawl as slow variable in Phoenix, Arizona. From 1990 to 2000, Phoenix grew by 47% to over 3.5 million people (US Census Bureau, 2000), with expected increase to go up to 7–8 million by 2030 (Berling-Wolff and Wu 2004). There has been a rapid conversion of agricultural land to urbanized land that earlier supported vast lowland of Sonoran desert and riparian vegetation. *Source*: Photo by Örjan Bodin, 2008

Rivers. Historically, the cradle of the Hohokam civilization (500–700 AD to 1400 AD), human settlement did not return until the reintroduction of agriculture in the 1860s, which led to almost exponential population growth as agricultural interests tapped into ground and canal water (Redman and Kinzig 2008). Today, Phoenix is the fifth largest city in the USA and one of the two fastest growing (Fig. 5).

Growth and geographic expansion of Phoenix (and many western US cities) from the 1950s was spurred by national scale changes; the development of air conditioning and the "suburban lifestyle" with a high cultural value of single family homes. The widespread ownership of detached homes was enabled by the availability of vast stretches of inexpensive land, the ubiquitous use of motor vehicles and the subvention of highways, cheap motor fuel, and home ownership. This cultural–political–economic complex can be viewed as a slow variable that has led to the dispersed urban layout of cities like Phoenix and the peripheries of cities around the world. However, this pattern has engendered several vulnerabilities that undermine its resilience. First, it requires the conversion of vast stretches of land that had previously been used for agriculture or as open space, each providing a variety of ecosystem services, while also producing urban spaces with exotic plants in sharp contrast with the undeveloped desert with native vegetation. Second, the dispersed pattern is highly consumptive of materials for infrastructure and residential construction. Third, and the most threatening, are the energy requirements of both the residences themselves and the distances that must be travelled, largely in single individual-occupied automobiles. As the price of energy increases, there is a risk of crossing a threshold and entering a downward economic spiral.

Urban expansion in this arid region (average annual rainfall of 180 mm) has been supported by water-supply projects. Reservoirs that impound surface runoff from the local Salt and Gila River catchments are paired with a canal transporting Colorado River water 500 km to Phoenix, and groundwater pumping that substantially exceeds natural recharge (Kupel 2003). Each of these was introduced as a "fix" to the water situation and yet cannot indefinitely support the urban system on its current trajectory (Gober 2007). The challenge increases with the uncertainty created by inter-annual variability of rainfall patterns, along with the specter of most climate change scenarios projecting significant reductions in precipitation and increasing temperatures. In this situation, urban water managers have come to rely on securing water through that farmers can profitably sell irrigated farmland. Hence, the growth of urban areas is linked to the retirement of irrigated lands, which is part of a global trend with serious implications for global and local food security further undermining resilience.

We note that in New Orleans, Cape Town, and Phoenix, there are cross-scale linkages that seem to erode resilience and bring to bear new types of positive feedbacks that will be difficult, if not impossible, to undo. While, for example, oil companies eroded the coastline of New Orleans to gain profit, the public (most of all poor citizens) lost the crucial ecosystem service of storm protection. In Cape Town, the economic legacies of oppressive apartheid policies have allowed the rich to overconsume space and water, undermining ecosystem services, while poorer citizens are forced to place their shacks in areas that cause them to erode biodiversity and local ecosystem services. In Phoenix, national policies, subventions, and technological innovations have created a dispersed urban layout requiring great consumption of energy, land, and water. In these human-dominated ecosystems, there are close relationships between social dynamics, structure and inequity, and the ability to sustain ecosystem services at different scales.

SECOND ARGUMENT: CROSS-SCALE INTERACTIONS BETWEEN TECHNICAL AND SOCIAL NETWORKS

Again, not exclusive to resilience theory (Allen et al. 1986), the idea that ecological systems are hierarchically organized in such a way that processes which operate on more or less the same timescales are more closely impacting on each other than those that operate at different timescales is one of the very powerful elements in the study of the principal resilience theorists. Indeed, Gunderson and Holling (Gunderson and Holling 2002), in their book *Panarchy*, make the nature and role of the interactions between processes operating at different scales the focus of attention. Leaving our three cities for a while, how would this relate to urban resilience?

First, it underlines the important shift made by geographers to view urban phenomena as occurring in "system of cities" where close relationships, whether through exchange, trade, migration, or other, permit the flow of energy, matter, and information among the cities in the system (e.g., Pumain et al. 1989; Batty 2008). This emphasizes that cities need to be viewed as *loci in multiple networks of relationships at different scales*, rather than as entities. How does that apply to the idea of cities as being composed of nested sets of social–ecological processes, and how could the dynamic interlinkages or panarchies among these multiple networks be related to resilience in urban and human-dominated ecosystems?

Social networks are different from ecological networks. Whereas the latter take the form of food-webs (or plant–pollinator networks, or species–habitat networks) that transfer energy and genetic information, social networks are self-constructed by society in a process of "alignment" or "co-ordination," best described as a continual recursive communication process that eventually allows different people to understand each other, share values and beliefs, and generally work together to achieve their aims. Through continual interaction with each other, transaction costs for communication are lowered, and more effective human collective action can emerge, alongside social structures and division of labor. Such social networks of recursive communication depend upon flows of matter, energy, and information that provide stakeholders (whether individuals, firms, or agencies) access to resources distributed throughout society. However, while matter and energy may provide people with necessary means of survival, they cannot be shared like information. In other words, flows of matter and energy alone could never have created durable human social institutions, let alone towns or societies. Indeed, human societies are held together by shared expectations, institutions, world-views, ideas, technical know-how, in short by a shared culture (van der Leeuw 2007), enacted and shaped through social networks.

As a consequence, it is the sharing of information that creates the channels through which energy and matter flow. Through recursive alignment and communication processes, material and energetic resources are identified by urban stakeholders in distant local places and ecosystems, channeled into society and transformed by human knowledge and labor in such a way that they are suitable for use, and again transformed during use into forms with higher entropy, which are then disposed of. In order to do all these activities, the hinterland is structured by socially networked urban stakeholders, which extend "tentacles" or organized channels beyond the city boundaries to collect the needed energy and material (e.g., oil in New Orleans, dammed water in Cape Town and Phoenix). The "fabric of society," then, consists of flows through multiple technical networks, held together by different kinds of social relations (kin, business, friendship, exchange, client-patron, power, etc.), and transmitting different combinations of the three basic commodities (matter, energy, and information). This is one way of viewing the hybridity of cities, as processes enacted through networks of social, cultural, ecological, and technical relations (Swyngedouw 1996).

In coming to grips with the resilience *of* cities (as parts in systems of cities), the idea of *panarchies* helps bring forth the fact that although the networks for various commodities overlap, it is not necessarily so: water, electricity, petroleum, and coal are transported, processed, and delivered in different ways (which is true of virtually all goods in everyday life that we do not collect or process ourselves, e.g., food). This indicates that the network dynamics out of which cities (and societies) emerge involve many different temporal rhythms and spatial distances played out in different configurations and domains. A crucial insight for urban planning and governance is that the resilience *of* cities should be viewed as determined by the interplay between different types of networks across spatial and temporal scales, including the social networks (of managers, technicians, policymakers, etc.) that create and maintain technical networks.

THIRD ARGUMENT: URBAN INNOVATIVE CAPACITY

Pursuing how social networks of recursive communication are channeling resources to the city, supporting and molding its reproduction and development, our third argument involves how such urban social networks also underpin innovation. Innovation is here seen as novel ways of doing things, or how new things can be made useful, and refers to incremental or radical changes in ideas, practices, and products; including novel ways of organizing society, changing its rules and institutions. Innovations can be framed as technical, social, socio-technical, or as we would argue, social–ecological, but are embodied and implemented through social networks of recursive communication and alignment. Drawing upon sociology, we will argue that innovation sits at the heart of understanding resilience and transformative capacity in human-dominated systems, a statement further developed and exemplified in the fourth argument.

In support of our third argument, we turn to Bettencourt and colleagues (Bettencourt et al. 2007) who recently measured how the size of a city scales with a range of different indicators reflecting the role of energy, population and information in urban dynamics. Using population as the measure of city size, these indicators revealed three important patterns:

- Proxies for energy consumption scale sub-linearly with urban size, indicating that when cities grow, they become more energy efficient;
- As is to be expected, the number of basic service providers (bakeries, schools, etc.) scales linearly with urban size;
- Surprisingly however, the proxies related to innovation and new wealth creation (such as number of patents, number of employees in research, and wealth per capita) scale super-linearly with urban size, i.e., increase faster than the population (along with more negative social indicators such as crime rate and HIV-infected persons).

This indicates that a key driver behind urban growth is innovation (not just economies of scale in energy consumption). Further, through its tight linkage to economic value creation, urban innovation, especially technical innovation as measured here, is in large part responsible for the attractiveness of a city, i.e., the degree to which individual stakeholders are willing to locate there, to invest in it, and to collaborate with others in it; a process that consequently drives the emergence and development of social networks. Also social innovation, for instance the organization of public transport or day-care for children, can improve city life and the attractiveness of a city.

Taken together, urban innovation influences the ability to sustain ecosystem services, both locally and far from urban areas, and in positive and negative ways. On the one hand, urban innovation drives urban growth, which in turn structures local ecosystems regionally and throughout the world (and increasingly so through the rapid urbanization worldwide). On the other hand, urban innovation, embodied through recursive communication among various stakeholders, holds a potential to identify novel ways of sustaining resources to cities and systems of cities, or as put in the previous section, to change the alignment between technical and social networks. This, we believe, underlines the need for a re-consideration of resilience theory when considering cities and human-dominated ecosystems because it introduces the role of recursive information processing in all aspects of system dynamics (e.g., van der Leeuw 2007). Furthermore, this socially structured information processing could ultimately change our perspective on social–ecological dynamics altogether, including in landscapes not dominated by humans but in which they nevertheless play a role.

FOURTH ARGUMENT: HARNESSING URBAN INNOVATION ACROSS SCALES

The argument thus far leads to two complementary conclusions. On the one hand, we believe that sustainability and resilience depend on a society's innovative capacity, and on the other, we see clearly that solutions must be found by innovating in urban systems at different scales and across sectors. This firmly frames the urban system as an opportunity *for* sustainability and drives us to recognize that the answer to increased resilience might not lie in its ecological dimension, but rather in the social. In order to build resilience and face uncertainty and change means to harness the interactions between stakeholders. This requires an involvement of society in its broadest sense towards a change of culture that makes "collaboration" between society and the environment (rather than mere "interaction") the central focus of attention.

However, to harness urban innovation, we need to understand *why* innovation is more pronounced in cities than in rural areas. The answer lies in the concentration of population in cities: the more people interact through recursive alignment processes, the more cognitive dimensions exist within the interactive group, leading to that more problems can be tackled with quicker accumulation of knowledge. This in turn allows the cognition of new problems and even more generation of knowledge in a continuous feedback loop (cf. van der Leeuw and McGlade 1993; van der Leeuw and Aschan-Leygonie 2005).

Based on a social network model of cities, Arbesman, Kleinberg and Strogatz (Arbesman et al. 2009) take this explanation further. They argue (with reference to Granovetter 1973) that bigger cities generate more innovations because they generate more interaction between people that are *socially distant* to each other (i.e., not family or friends). Such long-distance (or weak) ties means that information that has not met before, meets more frequently the bigger the city is, which aggregates to increased innovation at the urban level (Arbesman et al. 2009).[4]

Two lessons seem clear: there is a need to nurture an overall cultural criticism of policies and knowledge production that de-link nature from society, and a need to develop meeting arenas that can generate long-distance ties between stakeholders at different scales and sectors. The arenas should serve to nurture "experiments" to engage with social–ecological dynamics, and as construction sites for discourses that articulate cities as reciprocal parts in dynamic landscapes and as constituted out of social–ecological processes. These discourses should serve to steer innovations toward more sustainable solutions, practices, and institutions. Although our case cities are by no means ideal, we have found telling efforts on how to harness urban innovation in such ways.

In New Orleans, hurricane Katrina sparked novel collaborations and an interdisciplinary knowledge production that meshed urban planning with coastal science, ecology, engineering, architecture, and landscape architecture (Birch and Wachter 2006; Costanza et al. 2006; Laska and Morrow 2006; Lopez 2006; Blakely 2007; CPRA 2007; LRA 2007; Rodiek 2007; Meffert 2008; Törnqvist and Meffert 2008). Given that deltaic cities like New Orleans will likely experience 3-10 mm per year of relative sea level rise in the next 50 years (Törnqvist et al. 2008), current expert debates concerning the re-organization of the city emphasize: planning with the regional hydrology and propensity for flooding in mind (high-density residential areas on higher ground and lower in floodable areas); remake landscapes through "natural" processes (e.g., divert the Mississippi River to rebuild coastal wetlands in protection of storm surges); increase local flood disaster preparedness through landscape interventions on a neighborhood scale with terraces, polders, and drainage enhancements (bayous, canals, and permeable surfaces); and maximize community participation to restore and nurture social capital (CPRA 2007; LRA 2007).

All of these reflect the change of perspective to which we have referred above, placing the city as a reciprocal part of a dynamic landscape and a regional ecosystem. However, the transitioning of social–ecological systems toward increased resilience and a fair distribution of ecosystem services needs to also engage in the culture and politics of space. While a general idea in New Orleans is to transform lower lying areas to historically marshy states (or to urban parks), such expert laden suggestions are fiercely contested and contains racial and political tensions since African-American communities have historically been pushed into those vulnerable areas below sea-level. Not merely social arenas of deliberation, but also political and social movements, which can broker these conflicts and negotiate more equitable and fair solutions, seems crucially important in New Orleans. More generally, social movements seem important in any social–ecological system going through a re-organizational phase, since otherwise, the resilience being built post-disaster, will be conditioned and entangled with systems of oppression and an unequal distribution of ecosystem services (Ernstson 2008; Ernstson et al. 2008). In this respect, the residents of New Orleans, who form part of self-organized communities-of-practices that engage in tree planting and community greening projects, are important features of the social dynamics that interact to constitute the post-Katrina social–ecological system (Keith Tidball, pers. comm.). These evolving "civic ecology" practices (Tidball and Krasny 2007), which are partly supported by universities and the City of New Orleans, not only seem to empower their participants, build social capital and sense of place, but also play a role in generating ecosystem services such as improved mitigation of flooding, better air quality, cooling houses (with lower energy consumption), and re-introducing habitats, and landscape ecological functions. They furthermore represent a possibility for collaborative ecosystem management as they forge social–ecological feedbacks through localized learning of ecosystem dynamics (Krasny and Tidball 2009; Barthel et al. 2010; Ernstson et al. 2010), and could be key collective agents in nurturing a cultural change in how residents enact the city as a culture–nature space.

Cape Town follows a similar trajectory with a mix of top-down planning and community-based initiatives. In order to protect natural resources within the city, the City of Cape Town used conservation planning to identify a "biodiversity network" of threatened green area ecosystems and species. In order to counter degradation of these sites by invasion of alien plants, illegal dumping, urban development projects, and land invasions by informal settlements, the City of Cape Town engaged with a range of partners to nurture a culture of civil society involvement in

[4] Arbesman et al. (2009) mention two other possible explanations to urban innovation: that cities simply have more highly educated people, and more transient people that bring new ideas. However, the social networks of cities—especially the great number of long-distance (weak) ties—constitute a fundamental difference between urban and non-urban systems.

conservation of biodiversity through community use of green open areas.

One such partnership is the project Cape Flats Nature developed together with the parastatal South African National Biodiversity Institute (SANBI). This project has focused on a small selection of sites in the biodiversity network, aiming at "developing an alternative, social nature conservation practice in impoverished urban areas" that places "people's needs and basic human rights […] at the centre of nature conservation" (CFN 2006). The project engages local organizations and schools to explore how local ecosystems provide ecosystem services such as flood mitigation (involving wetland restoration), wind protection, and offering educational and recreational space. In order to achieve this, the project facilitates formation of local "champion forums" to develop local and credible leadership, as well as working with the City of Cape Town on developing a people-centered orientation for municipal nature conservation officers.

Another approach to involve local people in conservation activities is to address it via poverty alleviation. For instance, the "Working for Water" and "Working for Wetlands" national job creation programs, provide work and training in projects that remove invasive non-indigenous plant species (Fig. 6), and restore aquatic ecosystems (van Wilgen et al. 1998; Falkenmark 2003). Less interventionist, but also an important contribution of civil society, is the involvement of voluntary care groups, often as middle-class "friends" groups motivated to maintain the local neighborhood environments by aesthetic, ethical, and heritage considerations. Many urban ecosystems such as river corridors, wetlands, or even open commonage providing habitat for iconic species of plants, birds, or amphibians, receive conservation benefit from this type of engagement.

Fig. 6 Re-creating wetlands in the Tokai Forest, Cape Town. Through forging novel social ties across sectors and scales, biodiversity rich wetlands are re-created through collaboration between local civil society groups, the South African National Biodiversity Institute, and the Working for Wetlands program that employs unemployed low-skilled workers. *Source*: Photo by Henrik Ernstson, 2008

At a larger scale, guided by the Water Act of 1998, sustainable management of water resources (Falkenmark 2003) is facilitated by input from many sectors of society through establishment of structures such as Water User Associations. These link water users and stakeholders, including wine farmers, nature conservation organizations and urban municipalities such as the City of Cape Town, in negotiating shared long-term plans for the generation and protection of ecosystem services. Deliberative arenas such as these are potentially potent in addressing broader social, ecological, and economic dynamics in the region, including incentives for development of a functional model for "payment for ecosystem services" (Turpie et al. 2008), and in forging novel social networks across sectors and scales. The newly formed African Centre for Cities at the University of Cape Town, with its CitiLabs engaging in on-the-ground urban problems, provides another emergent arena for cross-scale and cross-sector engagement between academics and practitioners (ACC 2009).

In Phoenix, efforts have been made to organize the 20 separate municipalities in the region to face social–ecological uncertainties. A "Sustainable Cities Network" is convened and staffed by the Arizona State University and administered by member cities and used as a forum for sharing "best practices" such as on installing more solar power, or developing new mobility options. Another response relates directly to the uncertainties of water provisioning. While water managers work to meet demand at the scale of individual municipalities or even smaller units, and at a time frame of the next few years, the supply of water is being driven by global patterns that will take decades to play out and with impacts at region-wide scale.

In an effort to develop decision-support tools under these conditions of climate uncertainty and to form a bridging organization between university researchers and the many entities that manage water allocations and establish policy, the Decision Center for a Desert City (DCDC 2009) was established with funding from the US National Science Foundation. A central scientific activity of DCDC has been to develop at systems dynamics modeling representation (WaterSim) of the interactions of climate variability, climate change scenarios, population growth, land use patterns, agricultural retirement, and conservation measures to project water availability. WaterSim has been presented to numerous groups of citizens, public officials, and managers including a front page article in the largest newspaper and a scaled down version available on the web (DCDC 2009). Two efforts seem to directly engage in generating novel "long-distance ties" and forge novel social networks across sectors and scales. The first being a group of 60 water managers and policy makers that have participated in multiple small group meetings to evaluate and help refine WaterSim given each of their own perspectives (White et al. 2008). DCDC has, moreover, convened a second set of meetings, Water Dialogues, with a more loosely defined membership of university faculty and students, and various water managers and interested citizens who attend a monthly meeting to share information and ideas in response to an invited speaker on local issues.

CONCLUSION

Contemporary urbanization is riddled with uncertainty. Interlinked with climate change, migration, and economic crisis, urbanization has become a dynamic, multi-scalar, and complex process where no actor, or set of actors, can have full knowledge or full control. In this article, we have visited three cities and drawn upon systems analysis to shape an argument that uncertainty needs to be faced with experimentation, learning, and innovation, and—since innovation reaches extreme levels in cities—that the urban should be framed as an opportunity *for* sustainability. Furthermore, since urban innovation is a driver of urbanization, it influences (often negatively) ecosystems across the globe, which places urban innovation at the heart of resilience for well-nigh all ecosystems. The challenge lies in harnessing urban innovation toward sustainability and learning at various scales and across sectors. This implies the need to construct discourses that undermine the artificial and culturally biased notion that society and cities are separated from nature and countryside, and instead view cities as reciprocal parts of regional ecosystems and dynamic landscapes, constituted out of social–ecological processes from ecosystems across the globe (Luccarelli 1996).[5]

An immediate task for research is, therefore, to explore how uncertainty and ecosystem services can be integrated into the social practice of urban planning. Here, framing—the construction of narratives explaining the nature of a problem and how it might be addressed—seems to be a key issue (Snow et al. 1986; Leach 2008). What are the social practices of framing that tend to cut out uncertainties and present systems as stable and society as de-linked from nature? What actors, institutions, and practices sustain a static bi-polar world and preclude resilient social–ecological approaches to urban problems? And what arenas, experiments, and practical interventions run counter and instead sustain uncertainty and hybrid social–ecological world-views? Frameworks for addressing the city-scale and resilience *in* cities exist. From the (non-urban) resilience discourse, we have "co-management" and "adaptive governance" (Carlsson and Berkes 2005; Folke et al. 2005), that could fruitfully be merged with ideas of "ecologizing planning" (Murdoch 2006), and "communicative" and "collaborative" planning (Graham and Healey 1999; Goldstein 2009) taken from post-structuralist geography and urban planning theory. However, there is a lack of theory that links the scale of the city (resilience *in* cities), to the scale of "systems of cities" (resilience *of* cities). More explicitly, we lack theory to analyze the panarchies of urban networks, i.e., the dynamic interlinkages between social and technical networks that sustain energy, matter, and information, and how these dynamic networks influence ecological networks and the capacity to generate local-to-regional ecosystem services (but see Alberti and Marzluff 2004; Pickett et al. 2008). For instance, how do technical networks shape urban land-use patterns and influence urban ecosystems? Efforts in these directions should also integrate urban political ecology (Heynen et al. 2006) to make explicit that planning and governance is always entangled in politics (Flyvbjerg 1998).

The immediate task for policy is to push for a radical shift in the mode of knowledge production and application. Given the stressed ecosystems of the planet (MA 2005), we need an institutional shift from yesterday's industrial economy and current innovative economy (that accepts waste and the erosion of ecosystems), to an "ecological economy" where competitiveness should also lie in how effectively one uses and/or support the generation of ecosystem services (C. Wilkinson, pers. comm.). Simultaneously, policy should move toward (i) defining the scales and places of intervention (resilience *in* and *of* cities) and bring together a wide array of stakeholders; (ii) changing the role of scientists vis-à-vis policy through funding research that value processes and methodologies over scientific breakthrough and technological fixes (i.e., providing incentives for scientists to move from being "data providers" to become connective actors across scales and sectors); (iii) creating a sense of urgency among stakeholders and the public on immediate dependencies on ecosystems locally, regionally, and globally through building institutions that monitor ecosystem services, and foster on-the-ground experiments and learning; and (iv) placing access and equity to ecosystem services—and therefore politics—at the heart of resilience building (Armitage and Johnson 2006; Ernstson 2008).

[5] We note how this also partly resonates with ideas from the early 1900's as articulated by for instance the american intellectual and regional planning theorist Luis Mumford (1895–1990) (Luccarelli 1996).

In order to do this, time and resources must be invested in the very process of knowledge networking. As this implies devolution of power and potential weakening of control by governments, there is bound to be stiff resistance to this process. Here, civil society organizations and social movements, who also concentrate in urban areas—from Slum Dwellers International, Transition Towns, and those mobilizing on climate change and unjust globalization, to urban farming and protection of green space—will be key factors in forging structural social change (Carley et al. 2001), and in co-constructing framings that interlink injustices with the distribution of ecosystem services (Ernstson 2008).

As we have argued, the urban arena provides a public space for the cross-fertilization of minds and disciplines, enabling a new perspective on human-in-nature, one that could undermine the divide between society and nature, the pristine and the human-dominated, and contribute to the creation of a new language, with signs, concepts, words, tools, and institutions that could facilitate meaningful politics to broker conflicts and establish responsible environmental stewardship at the heart of public interest. We indeed believe that there is a potential in developing new forms of knowledge, creating new arenas and a new set of norms and institutions to nurture urban resilience.

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