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Co-adapting societal and ecological interactions following large disturbances in urban park woodlands

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Abstract The responses of urban park woodlands to large disturbances provide the opportunity to identify and examine linkages in social-ecological systems in urban landscapes. We propose that the Panarchy model consisting of hierarchically nested adaptive cycles provides a useful framework to evaluate those linkages. We use two case studies as examples – Cherokee Park in Louisville, Kentucky, USA and Tijuca Forest in Rio de Janeiro, Brazil. In the Cherokee Park case study, the disturbance, a destructive tornado, triggered bottom-up societal responses that created new institutions that influenced park management and shifted the woodland community from a successional pathway dominated by invasive exotic plants to one where native plant species are regaining importance. In the Tijuca Forest example, the disturbance, large scale land-use changes during the 18th century, triggered primarily top-down societal responses to create the world's largest urban forest through a transformative programme of intensive multispecies forest replanting and management. Currently, fine scale disturbances – primarily anthropogenically caused fire – threaten portions of Tijuca Forest through loss of forest structure and establishment of flammable invasive plants, and again elicited top-down societal responses to stop further destruction and promote greater native plant regeneration. These case studies illustrate that either natural or anthropogenic disturbances to natural systems can alter the direction and magnitude of interactions between social and natural domains in urban landscapes in a co-adaptive manner that alters structures and processes in both system components.

Key words: adaptive cycle, disturbance, panarchy, resilience, social-ecological system, urban ecology, urban park.

INTRODUCTION

Disturbances in ecology have long been recognized as both destructive and creative forces in the environment. Ecologically, a disturbance rapidly changes resource availability, which provides opportunities for reorganization in biological communities (Pickett & White 1985). At landscape scales this results in heterogeneity in patch types due to the existence of different communities in various stages of recovery from disturbance. As a consequence, increased species diversity and variation in ecosystem productivity are maintained at large spatial scales (Chapin *et al*. 2002). Socially, a disturbance can alter the amount and distribution of capital – for example financial, human, physical and natural – thus initiating reorganization of social institutions and networks (Abel *et al*. 2006).

Most ecological studies of disturbance effects on terrestrial ecosystems have been conducted in natural areas far from human habitation. In this paper, we examine the responses of urban park woodlands to disturbance events. This necessitates inclusion of subsequent societal responses to the disturbance and the interactions between society and the ecological state of the urban park woodland. We focus here on the forested sectors of urban parks for several reasons. First, they are a common natural component of many urban ecosystems. Second, they vary in size and are embedded in different biophysical and social contexts (Zipperer *et al*. 1997). This variation will permit future cross-system comparisons of the influence of size and of geographic, biophysical and social contexts on urban woodland recovery. For example, large urban woodlands (e.g. >100 ha) may have a great deal of internal control over system state and response to disturbance, whereas smaller urban parks (<10 ha) are more open systems with little buffering capacity against inputs of matter, energy and species from their surroundings (Forman 1995). Therefore, responses to disturbance by urban woodland parks would depend on the high edge-to-interior ratios of the woodlands and interactions with the highly contrasting biophysical and social matrix in which they are embedded. Third, urban woodland parks are a unique category of natural capital, because they are managed not for direct economic profit-taking or resource extraction, but rather for their ecosystem services and cultural benefits to the local society. The communal nature of these parks and the cultural value people place on

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them are distinctive socioecological characteristics that may influence the recovery of these systems after disturbance.

Further, we focus on large intense disturbances due to their potential to trigger responses by the societal networks connected with parks. The ecological status of a park responds to changes in public attitudes and institutional capacities over decades (Zipperer & Zipperer 1992; Cramer 1993; Sauer 1998). By creating highly visible damage to ecological communities, large disturbances may cause more rapid and easily detectable shifts in societal perceptions and responses to park condition, and generate institutional crises that have both short- and long-term ramifications. Thus, despite the fact that some chronic and less visible disturbances (e.g. trampling, soil erosion) may be important to the sustainability and resilience of a park ecosystem, exploring societal-park exchanges after large disturbances may provide opportunities to identify and study larger-scale interactions between society and natural areas in cities.

Therefore, exploring how urban surroundings alter the recovery responses of park woodland communities to disturbance requires us to consider not only the endogenous response capacity and biophysical context of these woodlands, but also societal connectivity with them. Indeed, societal connectivity itself may change in magnitude and direction by a disturbance as well. These socioecological exchanges can have important implications for the direction and rates of response of both natural and societal systems, because informal and formal societal networks and institutions may be altered by park disturbance. Thus, large disturbances to urban parks may constitute a natural experiment that reveals or brings into existence the emerging properties and evolving feedbacks of a co-adapting social-ecological system. The nexus between people, parks and a non-linear change in state brought about by a large disturbance provides a microcosm for exploring how a social-ecological system functions, adapts and evolves, and becomes a means for determining the value placed on natural components of an urban system by different sectors of its populace.

It is also timely and practical to consider the topic of disturbances in cities and their implications for different components of urban green infrastructure. Cities throughout the world continue to grow rapidly, and change disturbance types and patterns in their regions (Sukopp & Starfinger 1999; Reice 2005). In addition, disturbance regimes across the planet are likely to change due to global warming and climate disruption, placing greater stress on cities and their capacity to manage the damage to built and green infrastructure, as well as to human lives. The degree to which both the built infrastructure and natural areas are simultaneously damaged by a particular disturbance event then becomes a critical consideration when managing natural components of cities for resistance or resilience to disturbance so that they can continue to provide ecological and cultural benefits to people.

In this paper we examine responses in socioecological relationships following a large disturbance in urban landscapes. We use two case studies – Cherokee Park in Louisville, Kentucky, USA and Tijuca Forest in Rio de Janeiro, Brazil. The purpose of presenting these case studies is not to test hypotheses in a traditional sense, but rather to provide historical analyses based on our interpretations of primary sources and available published data (Abel *et al*. 2006). Exploring and historically reconstructing the various behaviours and decisions made by urban people and institutions as they responded to park damage may help us understand the process of socioecological adaptation and generate hypotheses as to where adaptive capacity resides under different circumstances for improving not only the quality and sustainability of parks, but by extension other forms of urban green infrastructure and their ecosystem services. Because these responses and park outcomes are likely to be contingent on different disturbance and park characteristics, as well as on social context, we provide a list of factors (Table 1) as a starting place for developing a broader comparative typology across different cities and disturbance types in the future. To provide a foundation and framework for these interpretations, we have used the Adaptive Cycle and Panarchy concepts as proposed by Gunderson and Holling (2002).

PANARCHY: A MODEL FOR EXAMINING COMPLEXITY IN SOCIAL-ECOLOGICAL SYSTEMS

The Panarchy model (Holling 2001; Gunderson & Holling 2002), with its nested hierarchy of adaptive cycles, has been used to examine socioecological relationships principally for extractive communities (e.g. agrarian) and natural resource management (e.g. timber and fisheries), but has so far not been applied greatly to urban landscapes. A panarchy framework is useful because it can explicitly incorporate disturbance as a driver of change. The basic unit of a panarchy is the adaptive cycle (Fig. 1). At any scale, an adaptive cycle of an ecological, economic or social system moves through four phases of development (r, K, Ω, α). The r stage of growth or exploitation is followed by a K stage of maturation and consolidation (analogous to the r and K ecological strategies). As the system moves from r to K, connectedness increases among system components (e.g. park woodlands, people, institutions), and system potential (e.g. economic wealth, knowledge, social capital, ecological capital, species diversity) grows. At some point in the cycle, either external or internal forces may cause a sudden breakdown to a less

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Table 1. Some attributes for evaluating rates and directions of recovery of natural areas in urban parks to disturbance

Disturbance	Park	City
Disturbance properties	***Physical and ecological properties***	***City properties***
Type (e.g. wind, fire, flood, earthquake)	Size	Population size, density, diversity
Immediate cause (local human *vs.* not)	Topographic variation	Wealth sources, amount and distribution
Novel or normal to region	Habitat types	Governance type and departmental funding distribution
Intensity	Successional states (age)	Management agency and primary goals
Areal extent	Condition	***Social networks***
Frequency	Disturbance history	Functional diversity and redundancy of park advocates
Damage properties	Other current disturbances	Connectance of park advocates to internal power structures
Severity	Sensitivity to disturbance	Linkages to national and international power structures
Simultaneity of damage to city and park	Adjacent biophysical context	
Visibility of damage to public	Diversity of ecosystem services	
	Societal connectance properties	
	Adjacent socio-demographic context	
	Accessibility	
	Diversity of uses	
	Number of users and their profiles	
	Perceived park value	
	Perceived social or biotic uniqueness (compared to other local parks)	

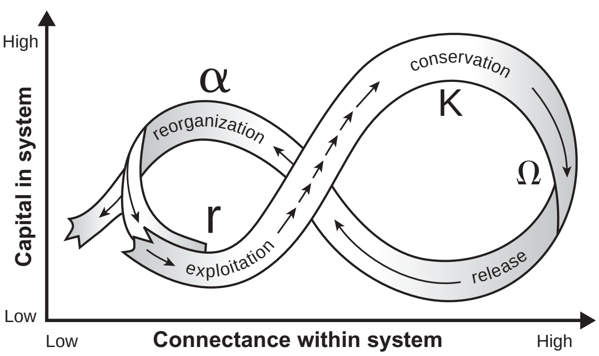

Fig. 1. An adaptive cycle, the basic unit of a hierarchical panarchy. This general cycle can represent many types of systems such as ecological, economic or social. The adaptive cycle consists of a front loop (r and K phases of development) where both connectance (x-axis) and capital (y-axis) within the system increases over time. At some point either an internal or external disturbance event causes the system to break down rapidly, releasing component units in a more disorganized state (omega (Ω)). As the back-loop (Ω and alpha (α) stages of the cycle) continues, loss of connectance permits experimentation with new rearrangements of components. During the α stage, uncertainty about the future system state is highest, but declines as failed experiments are winnowed out and surviving rearrangements grow during the next r phase of the cycle. Large disturbances in cities can play an important role in these adaptive cycles by triggering Ω phases and thereby creating new opportunities or templates for societal learning and restructuring during the α phase. Restructuring, however, is not always adaptive but can become maladaptive, depending on contingencies internal and external to the system. Modified from Fig. 2-1 in *Panarchy*, edited by L. H. Gunderson and C. S. Holling. © 2002 Island Press.

organized state (omega (Ω) stage). This destruction of connections permits new rearrangements of components (the alpha (α) reorganization stage). Thus the release stage provides opportunities for new 'players' (and new ideas for human society) to enter and become more prominent in the system, be they species, nutrients, individual people, citizen groups or institutions. At this stage in the cycle, the probability of several alternative future states is high. The system can reorganize and return to its former regime (i.e. exhibit resilience), shift to a different regime with similar structure but with changes in feedbacks and dominant processes, or transform into a new regime with novel state variables and feedbacks (Abel *et al.* 2006; Walker *et al.* 2006). As novel societal or ecological groups assemble, some succeed and others fail, and the adaptive cycle of r, K, Ω and α stages may then be repeated or the system may transition back into either the r or α stages without progressing to a K state (Walker *et al.* 2006). Therefore, the four-phase cycle progression itself is not necessarily a fixed sequence of events, that is, the cycle is not deterministic.

Because large disturbances in cities can be enormously destructive and visible, they can play an important role in these adaptive cycles by triggering Ω phases and creating opportunities or new templates for societal learning and restructuring during the α phase. These rearrangements of system components may then alter relationships between people and nature in ways that have the potential to improve the resiliency of the urban social-ecological system to future external shocks (adaptation) or not improve its resiliency (maladaptation).

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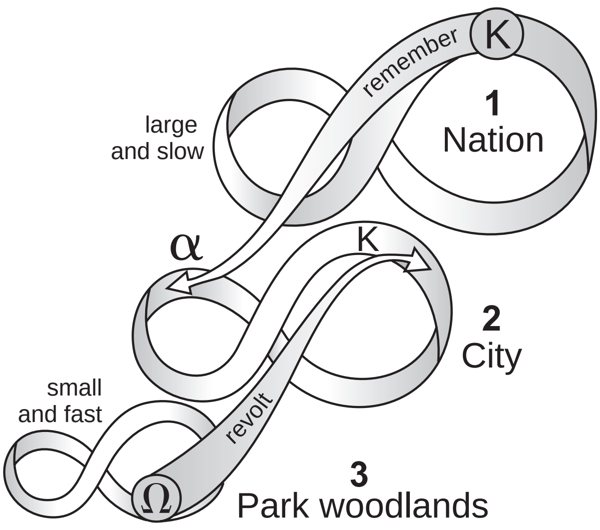

Fig. 2. A panarchy, which in this case consists of three hierarchically nested adaptive cycles, functioning at different spatial and temporal scales. In the examples used in this paper, the smallest cycling system is the park woodland community nested within the middle cycle representing the city scale, which in turn is nested within the largest national cycle. The rates of change for each cycle differ with the largest spatial scale (national) being the slowest. Therefore, each system is not necessarily synchronously phased with the others in terms of being in r, K, Ω and α stages of their cycles. Each system is connected to others and therefore influence each other across scales via two processes called remembrance (downscale movement of resources) and revolt (upscale communication or movement of material). Generally, a system must be in K phase to contribute material to smaller scale systems during remembrance processes. Revolts from a lower system can trigger Ω phases of destabilization in the higher order system. Modified from Fig. 3-10 in *Panarchy*, edited by L. H. Gunderson and C. S. Holling. © 2002 Island Press.

A panarchy consists of at least three adaptive cycles at different spatial scales all functioning at different rates, and hence not necessarily synchronously phased (Fig. 2). Large systems cycle more slowly than the smaller systems within them. These systems are interconnected and influence each other across scales by the processes of remembrance and revolt (Fig. 2). During remembrance transfers, larger cycles may potentially stabilize smaller ones by donating some accumulated capital (e.g. knowledge, financial resources, species) to a subsystem in its reorganization stage. To do this, the higher scale cycle must be in a stage of high connectance and capital accumulation, that is, in the K phase of its cycle. Systems with smaller, faster cycles may also connect upscale to larger systems via the process of revolt (e.g. epidemics, community activists, revolutionaries), which can trigger an Ω phase of destabilization in the higher order system. Resilience and a return to the system's former functionality are possible if the disturbance does not cause such large losses of natural and human capital that reassortment followed by reconnectance cannot be achieved. In that case, the entire societal-nature system remains in a more-or-less persistent state of impoverishment that will likely lack resistance or resilience to future disturbances and potentially degrade further via reinforcing feedback mechanisms.

The two case studies described herein (Cherokee Park and Tijuca Forest) can contribute to studies of social-ecological systems by examining in detail and over long periods (decades to centuries) how the societal domain responded to the collapse of a part of its natural domain due to large disturbances. Such urban examples can provide more dimensions to the growing predictive foundation for investigating societal resilience, adaptability and transformability (Walker *et al.* 2004; Gotts 2007). In particular, they showcase how social capital mobilized itself in response to large losses of ecological and cultural capital during the recovery back loop of their adaptive cycles. This critical phase has been comparatively less studied and understood by the resilience-and-society community, which has mainly focused on the causes of collapse (Abel *et al.* 2006; Walker *et al.* 2006). Our two case studies contrast the roles of functional and response diversity of social networks, social elites, adaptive governance and management, and cross-scale interactions (Walker *et al.* 2006) in promoting either the resilience or transformation of a natural component of a city after large disturbances. The long periods for which information is available for these two examples also permits iterations of their adaptive cycles to be examined. This therefore allows examination of how both the social and natural domains of these urban park systems may have changed together over time via reinforcing feedback loops (co-adaptation). To provide greater insight into the relationships between diverse social responses to disturbance and the recovery of woodland plant communities in urban parks, we describe in historically longitudinal detail the adaptive cycles of two parks with contrasting ecological and societal attributes, rather than describe more superficially the responses of more parks.

CASE STUDY 1: A TORNADO IN CHEROKEE PARK, LOUISVILLE, KENTUCKY, USA

Tornado damage to the park

On 3 April 1974, a 400-km h^{-1} tornado cut a 16-km path across residential neighbourhoods and Cherokee Park, an 80-year-old, 166-ha Olmsted Park, in Louisville, KY (NOAA 1974, Thomas *et al.* 1974; Hoxit & Chappell 1975). In minutes the tornado destroyed nearly 2200 mature trees (about 75% of the park's

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mature tree population; Share 1976); the canopy in half of the naturally wooded area was destroyed. The immediate reforestation and other subsequent responses by institutions and citizen's groups over the next 30 years became important determinants of the successional pathways taken by the park's woodland communities. To understand both the biological and human community's responses to disturbance, a brief examination of the historical connections between the local people and Cherokee Park is necessary. Within a panarchy framework, this history constitutes the pre-disturbance 'front loop' of an adaptive cycle, namely the r (growth/exploitation) and K (consolidation/institutionalization) phases of the growth and maturation of the park's woodland communities, as well as that of the city-scale institutions and public groups (abbreviated as City herein) that created, managed or used the park.

Park history and the Olmsted legacy (r through K phases for city-scale and woodland cycles)

In 1890, Cherokee Park and the rest of Louisville's park system came into existence due to persistent bottom-up demand by an active group of local leaders (Courier-Journal 5 June 1887; Levee 1992). In 1891, the firm of the renowned Frederick Law Olmsted was hired to begin work on Louisville's Public Park system including Cherokee Park. This action started 40 years of involvement among city government, the social elite, and Olmsted and his firm's successors, who created 16 parks and many neighbourhood subdivisions (some surrounding Cherokee Park) (Kramer *et al*. 1988). In addition, the Olmsted firm landscaped private estates of many local wealthy families (Kramer *et al*. 1988), who later influenced the city's response to the tornado damage in 1974.

Although the interior of Cherokee Park already contained naturally wooded areas, by the end of 1893 the Olmsted firm had overseen the planting of 17 706 trees and shrubs (Levee 1992). Although mainly native trees and shrubs were used, non-native species were planted (Richardson 1974; Beveridge & Levee 1992) including the following exotic invasives: bush and vine honeysuckles (*Lonicera* spp.), privet (*Ligustrum* spp.), buckthorn (*Rhamnus cathartica*) and groundcovers like periwinkle (*Vinca minor*), wintercreeper (*Euonymus fortunei*), English Ivy (*Hedera helix*) and ground ivy (*Glechoma hederacea*). After the Olmsted firm's departure in 1934, the natural areas came under a period of deferred management, resulting in exotic shrubs and vines becoming more prevalent in the 1950s through the 1970s (Richardson 1974; Louisville Olmsted Parks Conservancy 1994). Consequently, invasive woody species had become widespread in the park's woodlands when the tornado struck.

Between 1934 and 1970, active recreation gained popularity in the park, a marked deviation from the original Olmsted vision. Recreational uses included golf, tennis, baseball, horseback riding, playgrounds, bait-casting platforms along a pond, a dance hall and even a camp for auto-tourists (Anonymous 1938). This change in management objectives created a new state regime that had two effects on the park's woodlands. First, funds were reallocated from woodland to recreation management. The deferred woodland management resulted in the loss of the Park Department's institutional memory of the Olmsted plans and legacy (Anita Solomon, former Metro Parks Planner, pers. comm. 2009). The woodlands at this stage were of mixed age (ecologically mostly in r phase with some areas approaching K phase), but became dominated by invasive shrubs and vines. The second effect of this management shift was the rise of multiple active uses that appealed to a greater diversity of people, including working families, and not just the social elite. This democratization in park use may have fostered more widespread personal bonds with the park, ones with the potential to transcend generations through family tradition and personal remembrance, and served to increase social connectivity between the park and a greater diversity of people (city-scale connectivity with park in K phase). Thus, greater active recreational access may have contributed to the public's later broad and deeply emotional response to the tornado damage.

Immediate responses to the tornado (Ω and α phases for city cycle; Ω, α and r phases for woodland cycle)

The tornado was an external nature-caused event that triggered a simultaneous Ω-phase collapse for both social and ecological systems. The highly visible damage to the trees at the woodland scale of this panarchy (Fig. 2) triggered a form of 'revolt' of immediate and emotional responses from the public and press (Thomas *et al*. 1974). Abel *et al*. (2006) reported a similar effect for agricultural systems in Australia. This 'revolt' represented a cross-scale influence that contributed to both the short-term and longer-lasting attention the park received from local governmental agencies at the city scale of this panarchy. Within a week of the tornado, the mayor appointed an advisory committee of 26 influential citizens. Park administrators had also set into motion top-down (institutional) processes for restoration (Rau 1975) (city scale moves from an Ω to an α phase). The addition of the citizenry board actually reestablished and reemphasized a feedback loop that originally occurred during park development in 1891, one of functionally diverse governance over park affairs, which has been proposed to be an important component of system adaptability

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(Walker *et al.* 2006). The disturbance and reestablishment of this broader social connectance with park condition created new and more diverse opportunities for reorganization and resource allocation, as witnessed by the subsequent discussion on directions for park restoration. By April 22, vigorous debates erupted over future uses for the park (city scale in an α phase when alternative future states are most possible) in response to a damage assessment report and a general plan for clean-up and fund raising (Richardson 1974). The mayor and Parks Department were inundated with requests for more sports facilities, such as baseball fields and an expanded golf course (Share 1976). Older ideas such as creating a botanical garden and building an amphitheatre were also resurrected. Any or all of these options would have decreased space for natural areas, an action that dismayed other citizens, who wanted the internal road system to be closed to automobile traffic and the Olmsted legacy restored (archived memos and letters of Carl Bradley, Director of Parks).

During this α phase at the city scale, the direction of park restoration was uncertain, but three remembrance factors (Fig. 2), one at the city scale and two at the national scale, determined the park and the woodland's fate – a return to the original Olmsted plan. The mayor's advisory committee, composed primarily of socially prominent people familiar with the park's legacy, insisted that the park be restored based on the original Olmsted blueprints (Rau 1975). Unfortunately, the original plans in Louisville were lost, but a copy was discovered in December 1974 archived in the Library of Congress in Washington, D.C (A. Solomon, pers. comm. 2009; Richardson & Hudak 1974). Another remembrance factor at the national scale, critical to the direction of the park restoration, was the passage of the Federal Disaster Relief Act by Congress in early 1974. The Act allowed federal financial assistance for restoring damaged parks through the Federal Disaster Assistance Program. Louisville successfully obtained these funds, but funds could only be used to return a park to its former condition (Share 1976). Given the city's difficult financial circumstances, the new recreation options were dropped, and resource allocations were committed to restore the park to pre-storm conditions including implementation of the Olmsted design (the adaptive cycle at the city scale moved from α to r phase). A total of $235 000 was secured from the federal government and another $100 000 was raised by a citizen-run nonprofit organization, Trees Inc. (Share 1976; Manning 1984). So, these cross-scale remembrance transfers of archived knowledge and federal funds enabled the ecological system to return to an earlier state regime (i.e. to exhibit resilience) and significantly enhanced the adaptive capacity of the social domain. However, reforestation efforts did not begin for 2 years, a lag that had serious implications for the long-term success of the woodland restoration.

Ecologically, the tornado had devastating effects on the woodland park through canopy damage and the loss of mature trees. As a result of the mismatch in adaptive cycle rates between the city and the woodland plant community, the woodland community proceeded immediately from its α phase to a rapidly growing but unmanaged r-phase community. Given the open canopy and disturbed soil conditions due to log removal, existing invasive shrubs and vines benefited from the 2-year delay in restoration. Initial restoration efforts in Cherokee Park began in January 1976 and lasted through March 1976 with the planting of 2200 trees and about 5000 shrubs (Share 1976). Trees were primarily deciduous natives selected for having minimal maintenance requirements in anticipation that park forestry staffing would be too small to address tree maintenance needs (Johnson, Johnson and Roy, Inc. 1975). Shrubs were native, except for five invasive exotic species (three *Lonicera* species, *Rhamnus frangula* and *Berberis thunbergii*) (Johnson, Johnson and Roy, Inc. 1975). After these initial restoration efforts were completed, the general feeling within the Parks Department was that the Parks Department had done its best to 'fix the forest' and it was now 'time for the land to heal itself' (A. Solomon, pers. comm. 2009).

Longer-term responses to disturbance (prolonged α phase for city-scale cycle; Ω–α–r cyclic 'trap' for woodland ecological cycle)

Johnson, Johnson and Roy, the consultants hired for the restoration effort, predicted that the park woodlands would take about 25 years to begin to look like a forest again, but only with proper care and maintenance (Share 1976). However, during the decade following the restoration effort, the Parks Department once again focused resource allocation on maintaining recreational facilities in city parks, and so deferred forestry management (A. Solomon, pers. comm. 2009). Unfortunately, the presumed beneficial notion of letting nature 'heal' and take its course had serious ramifications for the subsequent health of the park woodlands as it became choked with invasive shrubs and vines. Woodland succession by native species appeared to stall in a prolonged r phase of development. In panarchy terms, the woodland ecological cycle did not move from an r phase into a more stable K phase, but entered into a different state regime with altered structure, function and feedbacks. At the same time the degree of connectedness between city-scale management and the woodlands declined, moving park management back into an α phase with respect to the park's woodlands. Consequently, the

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resilient capacity of the original native woodland communities declined, as invasive shrubs and vines dominated for both ecological and societal reasons.

Although the importance of feedback from the citizen advisory committee waned, individual advocacy from members of the social elite remained and pressured the Parks Department to secure a seed grant in the early 1980s from the new and federally funded Urban Parks and Recreation Program to start a non-profit park advocacy organization, the Louisville Friends of Olmsted Parks (LFOP). Once again federally available funds provided a cross-scale remembrance influence that enabled the formation of a citizenry group that increased the adaptive capacity of the Parks Department to meet the needs of woodland management. The creation of a bottom-up park advocacy group shortly thereafter shifted park management out of the α phase into a new r phase of increasing connectance and capital at the city scale.

Co-adaptation and the evolution of a public–private partnership (city scale moves from r to K phases; woodland ecological scale moves from α to r)

By 1989, the LFOP evolved into the stronger Louisville Olmsted Parks Conservancy (LOPC) with a public–private partnership becoming formally established between the Louisville Metro Parks Department and the LOPC to share management of the city's 16 Olmsted Parks (Louisville Olmsted Parks Conservancy 1994). Over time, this creation of greater functional diversity at the societal level has ultimately benefited native plant communities in Cherokee Park. The LOPC concentrated its efforts on managing the natural areas in these parks, whereas the Parks Department focused primarily on other park needs (e.g. mowing lawns, maintaining built facilities). This partnership has grown and matured through increased capacity and capital building (expanding K phase at the city scale). Over the last 20 years the Conservancy has successfully raised millions of dollars for an endowment fund, hired a larger expertise base and coordinated the activity of volunteer groups for restoring and managing park woodlands (Louisville Olmsted Parks Conservancy 1994; Perry & Samuels 1998).

As for the ecological status of the woodlands, LOPC has restored much of the woodland park area once devastated by the tornado and choked by exotic shrubs and vines. Currently many areas have a plant understory and overstory rich in native herbs, shrubs and trees, many of which have emerged from the seed bank (M. Carreiro, unpubl. data 2009). Through this external LOPC input, the regeneration layer of the forest is being restored through widespread eradication of invasive shrubs and vines. In panarchy terms, the woodland cycle is currently showing signs of shifting out of an Ω–α–r cyclic 'trap' and proceeding towards a K phase of succession more typical of a native deciduous forest in central Kentucky.

There are several lessons that can be learned from this case study. First, the tornado changed the relationship between people, institutions and the park in a non-linear manner. The destruction of so many mature trees provided a shocking visual signal to the community (i.e. a destabilizing revolt transfer upscale) that galvanized private citizens and public institutions into immediate action. While the tornado directly changed the woodland community by removing the mature tree canopy, it did so indirectly as well by mobilizing the human community from the bottom-up and top-down. This initiated an exchange between society and a natural woodland characterized by a co-adaptive socioecological dynamic that has lasted decades. This visual feedback of a tornado-damaged woodland engendered an immediate restoration response from society. However, because the immediate restoration effort was reactive and short-term, this allowed exotic species to dominate the woodlands. Nonetheless, the new social realignments and groups that formed shortly after the tornado left a remembrance legacy that evolved into a new park advocacy group (the LFOP) a decade later. As the degradation of the park's woodlands by exotic plants became harder to ignore, the public institution (Parks Department) became open to new approaches for managing the woodlands and partnered with the advocacy group for this purpose. The formation of the public–private partnership (Metro Parks and LOPC) that now co-manages Cherokee Park can be traced to these exchanges between people and the park that were set into motion by the 1974 tornado. By managing the woodlands more successfully than either partner could alone, this emergent institutional hybrid has had a measurable positive impact on the native plant species composition of this urban park woodland. Barthel *et al.* (2005) have described the evolution of other partnerships for co-managing biodiverse natural areas in Stockholm, Sweden, and Ruitenbeek and Cartier (2001) have also considered resource co-management to be an emergent property of social-ecological systems.

CASE STUDY 2: HUMAN-INDUCED DISTURBANCE IN TIJUCA FOREST, RIO DE JANEIRO, BRAZIL

Recurring fire damage in a forested park

This disturbance case study offers several contrasts with that of Cherokee Park (Table 1) that can inform the future development of a typology for socioecologi-

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cal responses to disturbances that involve urban natural areas. In this case, the current disturbance is not a single event but frequent fire (75 per year from 1991 to 2000), and not nature-driven but primarily human-caused, but with few of the fires intentionally set (Silva Matos *et al.* 2002). The habitat type is a broadleaf Atlantic rainforest growing on steep mountains up to 1000 m high where native plant communities are not adapted to frequent fires (da Silva & Silva Matos 2006). Consequently, these fires have not only altered native plant species composition, but also promoted invasion by exotic grasses that increase the likelihood of ignition, thereby creating a destabilizing feedback loop that favours ever more grass invasion (potentially creating an alternate system regime, *sensu* Walker *et al.* 2006). Unlike the smaller Cherokee Park, this 3300-ha forested park, in the heart of one of the largest cities in the world, is federally managed as a National Park Reserve for recreation, tourism, biodiversity conservation, research and education. While Cherokee Park is surrounded by upper middle and upper class neighbourhoods, Tijuca Park is surrounded mostly by middle class apartments and 'favelas' or slums. Additionally, in contrast with Cherokee Park, Rio's citizens are not frequent users of this forested park, partly because access is difficult for most (primarily by automobile), and because they prefer to use open spaces and beaches for recreation (Drummond 1996). This low level of local societal connectance may have implications for the degree to which local bottom-up forces participate and drive adaptive management options in the park in response to disturbance.

Tijuca Park history (r, K to Ω phases for the city; K to Ω phases for the native forest)

The history of this park's origins (Drummond 1996) offers possibilities for using the panarchy framework to examine the socioecological interactions between people and the Tijuca Forest over centuries. Historically, these interactions, in part driven by large-scale human disturbances interacting with climate extremes, first destroyed and then created this urban forest. Half of the park's current area was replanted *de novo* in the 19th century, not to create a park for recreation and leisure, but to restore an ecosystem service, water provision. There is no major river in Rio de Janeiro. Consequently, since the city's founding in 1565, the small but permanent streams running down the mountains of Tijuca were a major source of drinking water for the city. However, during the 1700s all except the steepest slopes were cleared for crops (primarily coffee), pasture and fuel. By 1820, coffee plantations were also abandoned, leaving behind denuded steep hillslopes. The human-caused and severe deforestation disturbance interacted with several years of intermittent drought and heavy rainfall to create both water shortages and flash floods in the city. The panarchy model identifies a cross-scale socioecological interaction: the Ω collapse of the forest community due to watershed-scale human disturbance caused an Ω phase crisis for people due to the lack of governmental responses to public need for water and protection from floods. Early on the Portuguese monarch residing in Rio de Janeiro at the time identified the need to address this crisis via reforestation, but subsequent socio-political upheaval (revolution for Brazilian independence) caused city- and national-scale cycles to shift to an Ω phase and reforestation was postponed. The country and city entered α to r phases during the reorganization of the political structure of the country in the 1830s, but still did not focus capital on solving their water crisis. Thus lack of a cross-scale subsidy for reforestation probably kept the native plant communities on the eroded Tijuca slopes in a disordered Ω–α–r cyclic trap for years due to long-lasting droughts during the nation-building period.

Recurring water shortages due to these severe droughts eventually led to major forest restoration efforts during the latter half of the 19th century. This enabled the native forest to move out of an Ω phase into α and r phases of recovery. Likewise, greater societal connectance with the forest was forged when a new government department was created for these restoration efforts. From 1861 to 1874, 16 km^2 of land were planted with over 60 000 tree seedlings (40 species, mostly native from neighbouring undamaged forests) (Drummond 1996). This pioneering multispecies reforestation effort successfully increased and stabilized the city's water supply from the streams, some of which still supply small sections of the city. The cross-scale interaction of this panarchy illustrates the reciprocal influence between ecological and social domains of urban ecosystems (Walker & Meyers 2004), namely that the Ω collapse of an ecosystem service, caused by intense and widespread forest clearing for agriculture (the disturbance), stimulated α and r phases in government reorganization and the creation of a new forested community over a large area (α to r phases for the forest).

With the water shortage problem temporarily stabilized, park management shifted to creating a public park within the Tijuca Forest for leisure and other cultural benefits. From 1877 to 1887, an additional 21 500 tree seedlings were planted, but these were mostly exotic ornamentals (Drummond 1996). However, once the city obtained water from distant sources in 1889, connectance between the socio-political system and the ecological system ended with stoppage of further forest reclamation. From 1890 to 1943, the Tijuca Forest entered a long period of deferred forest management. Although there was loss of societal

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dependence, natural tree regeneration continued, resulting in the diverse multilayered forest observed currently. In 1961, Tijuca National Park was created and eventually became a part of the Atlantic Rainforest World Biosphere Reserve. Today half of the Park's area consists of the human-created 150-year-old Tijuca Forest, which contains at least 30 native and 10 exotic tree species; the remaining area consists of disturbed original native forest and secondary growth stands. With increased ecological connectance, large sections of the forest can be considered to be in a K phase of development in the panarchy sense. The social system with respect to management also appears to be in a K phase of connectance from the forest perspective through a stable federal agency responsible for its management. However, compared to Cherokee Park, there is less connectance between local people and the forest with respect to its management.

Current responses to frequent fire disturbance (Ω, α and r phases for Tijuca Forest management; K to Ω phases for parts of the forest)

Currently, frequent fires are major threats to native biodiversity in Tijuca Park (da Silva & Silva Matos 2006). In the 1990s, 40% of fires of known origin resulted from religious practices, principally Festa Juninas balloons (Silva Matos *et al.* 2002). During this festival, balloons are held aloft by burning wax-soaked cotton and often drift and fall into Tijuca Park, igniting forest vegetation during the dry season in June. Because of this frequent disturbance, exotic grasses are replacing native communities in some locations. These grasses subsequently increase the flammability of the forest community, thus creating a positive feedback for an increase in fire frequency. In contrast with Cherokee Park, the public's visual cues of fire damage and shifts in biodiversity are relatively weak, because the damage is dispersed over a large area and because the exotic plant threat is mostly interpretable by experts, not the public. Unlike the tornado that damaged most of Cherokee Park, the frequent fires create localized Ω phase damage to relatively small portions of the entire forest. The lack of broad public concern and the scattered nature of the disturbances have engendered top-down responses by governance and by the managing agency through the passage of laws and ordinances, public education, and experimentation with novel restoration practices. However, these cross-scale interactions have not created the reciprocal bottom-up socioecological responses observed with Cherokee Park. For instance, in 1998, a law was enacted to prohibit manufacturing and flying of Festa Juninas balloons, but many to this day still continue the practice (Rohter 2002; da Silva & Silva Matos 2006).

Initially, management responses focused only on fire suppression (limiting the areal extent of the Ω phase disturbance) and not on restoring the α and r phases of forest community reorganization. Disturbed sites were subsequently invaded by exotic grasses, thus creating emergent exotic communities within the native forest. Recently, management has focused on both fire suppression and declining forest condition through the creation of plant communities with low flammability along the boundaries of forest stands (Silva Matos *et al.* 2002). These communities are composed of exotic species characterized by shade intolerance, so that their ability to spread into the forest is limited. Experiments have shown that fires were less frequent in locations with fire-resistant communities. By working with scientists to develop more fire-resistant, but non-invasive, barrier communities, the management community has enhanced its adaptive capacity by increasing the connectivity and functional diversity of its social networks, thus expanding their K phase development. Consequently, forest development in fire-disturbed areas is moving from Ω to α and r phases of recovery. Whether these plant communities will continue to develop or shift back into an Ω phase with future disturbances remains to be seen. To increase connectivity with local residents, management has also experimented with developing bottom-up participatory approaches (Briot *et al.* 2007). This management linkage to society is thought to be essential for achieving not only sustainability goals for the park, but also for the urban system as a whole (continual development of the K phase of the cycle with greater connectance among the forest, managers and people).

THE SOCIOECOLOGICAL CHARACTER OF DISTURBANCE RECOVERY IN URBAN NATURAL AREAS

Because large disturbances destabilize systems, there is much interest in determining factors that allow a system to return to a former state, or set them on new trajectories. Unlike large natural areas far from human settlement, where recovery after disturbance is determined primarily by the disturbance regime and the area's endogenous characteristics, understanding and predicting the response pathways of natural areas in cities will also require knowledge of the types, diversity and degrees of social connectance with those areas. The disturbed natural area can elicit a response from society, which may in turn change both natural and social urban domains over time. Therefore, park woodlands in cities are co-adapting social-ecological systems that may return to their original states after disturbance, or be transformed into novel systems by human decisions and resources. While the adaptive cycle framework can usefully organize and describe the

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temporal changes that occur after disturbance, disciplinary theories in ecology, sociology and other fields are needed to increase predictability (Walker *et al.* 2006). In addition, the components of the park system, or their surrogates, which may be managed for resilience to future disturbances, must be specified for effective restoration and adaptive management (Bennett *et al.* 2005).

What can we learn from our case studies about the characteristics of urban park woodlands that can affect their resilience to disturbance? Walker *et al.* (2004) identified four attributes of resilience: (i) latitude: the maximum amount a system can be changed before losing its ability to recover; (ii) resistance: the ease or difficulty of changing the system; (iii) precariousness: the distance between the system and a threshold of change; and (iv) panarchy: interactions and influences from states and dynamics at scales above and below the system. Woodland size can determine system vulnerability. Only part of the Tijuca Forest was affected by the fire disturbances, and thus the overall ecological resilience of the forest was maintained. In contrast, much of the area of Cherokee Park was significantly damaged by a single tornado. Thus, size may be correlated with latitude, resistance and precariousness. Park size is also likely related to resiliency. Due to their larger edge-to-interior ratios, substantial human assistance is needed for smaller urban woodlands to return to a state where native plant communities can retain their regenerative capacity, especially if invasive exotics dominate adjacent neighbourhoods and endure in the woodland seed bank. In Cherokee Park, continued woodland resilience is maintained only through large inputs of energy and funding from the LOPC, inputs that will have to be maintained continuously. Therefore, as recognized by Walker *et al.* (2004), organization of human capital will be a key requirement for promoting resilience or desirable transformations of urban park woodlands. In addition, the ability of the local human society to provide such assistance after a disturbance will be constrained by the degree to which people and the built environment were damaged by the disturbance and by economic and political cycles at national scales (panarchy). For example, funds for the Cherokee Park restoration and later adaptive management were made available from national sources, which were stable and wealthy (i.e. a nation in a K configuration), whereas despite the critical need for drinking water, reforestation of Tijuca hillslopes was delayed for decades by a country experiencing revolution and nation-building (i.e. in Ω and α states).

These two case studies also provide insight into the influence of the diversity of social connectance with the park on its resilience to disturbance. Middle and upper class residents adjacent to Cherokee Park influenced the recovery pathway taken after the tornado. By comparison, Tijuca's adjacent residents were not involved in managing the fire disturbance in the park, and may be causes of the damage. Consequently, current management in Tijuca is top-down with little bottom-up input. In the Cherokee Park example, the disturbance created reciprocal interactions between ecological and social systems that in turn influenced ecological resilience. Barthel *et al.* (2005) observed similar reciprocal interactions as citizenry responded to a disturbance (in this case land development) on the National Urban Park in Stockholm. Currently, ecological changes caused by localized disturbances have not significantly influenced social linkages with Tijuca Forest, although managers are trying to increase greater local connectance through workshops and other forms of reciprocal education.

CONCLUSIONS

While limited, our two urban disturbance examples do provide a framework, through the Panarchy model, to identify and examine socioecological interactions following a disturbance. The Panarchy model provides a useful framework for making additional cross-city comparisons of co-evolving interactions between people and nature after disturbances in urban systems, because the model recognizes: (i) cross-scale interactions above and below a system; (ii) change over time; (iii) analogous patterns of change (r, K, Ω, α) that can be applied to both social and natural domains in social-ecological systems; and (iv) feedbacks between both domains.

Some patterns begin to emerge that can serve as starting points for examining finer scale correlates of system behaviour. In cities, the ecological state of natural parks is tightly coupled to local societal behaviours, decisions and processes. Societal responses to disturbance damage in parks depend on both ecological and social factors operating at different temporal and spatial scales (Table 1). Examples of ecological factors include the severity, frequency and timing of the disturbance and its damage, vegetation composition and structure, areal extent of the forest community and its biophysical landscape context. Examples of social factors include the visibility of damage to the public, degree to which human and built infrastructure are simultaneously damaged, the legacy of public attachment to the park and its perceived uniqueness, degree of dependency on the park's ecological services, the diversity and integrity of local social networks after the disturbance, institutional flexibility, adaptive governance, and rescue by higher scale (national, international) governmental and non-governmental agents. Also, although the entire city may not be cascaded into an Ω phase crisis by the disturbance, the agencies managing the park can be.

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Over time this may create new social partnerships upon which the composition and integrity of the forest then becomes dependent.

Large-scale disturbances to natural areas in cities can be thought of as a natural experiment that can: (i) provide more detailed information about the socioecological linkages that exist between people and natural systems (and not just urban woodlands), and (ii) trigger a dynamic feedback between society and nature that over time may stimulate societal learning by causing top-down institutional rearrangements and/or by creating advocacy groups via bottom-up processes. Because learning may be constrained by larger scale conditions (such as economic downturns or degree of national assistance) and local contingencies, these socioecological exchanges will not necessarily result in positive (adaptive) outcomes for the quality of the natural area or the ecological services they render. Therefore, it will also be necessary to examine which conditions at local and larger scales may lead to maladaptive as well as adaptive recovery pathways. However, when outcomes are considered positive for people and the natural area, the initial large disturbance may reveal where adaptive capacity lies in different urban systems. In such cases, society can better identify the support policies and structures needed to improve urban resiliency to disturbance as a whole.

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REFERENCES

Abel N., Cumming D. H. M. & Anderies J. M. (2006) Collapse and reorganization in social-ecological systems: questions, some ideas, and policy implications. *Ecol. Soc.* **11,** 17. [Cited 5 October 2010.] Available from URL: http://www.ecologyandsociety.org/vol11/iss1/art17/

Anonymous (1938) Louisville Parks: a story of growth, 1890–1938. (Pamphlet in Louisville Olmsted Parks Conservancy archives).

Barthel S., Colding J., Elmqvist T. & Folke C. (2005) History and local management of a biodiversity-rich, urban cultural landscape. *Ecol. Soc.* **10,** 10. [Cited 31 March 2010.] Available from URL: http://www.ecologyandsociety.org/vol10/iss2/art10

Bennett E. M., Cumming G. S. & Peterson G. D. (2005) A systems model approach to determining resilience surrogates for case studies. *Ecosystems.* **8,** 945–57.

Beveridge C. E. & Levee A. A. (1992) Olmsted Documentary Resource for Louisville's Park Legacy: Cherokee, Iroquois and Shawnee Parks and the Parkways. (Louisville Park System Reports from 1892–1915 compiled for the Louisville Olmsted Parks Conservancy).

Briot J. P., Guyot P. & Irving M. (2007) Participatory simulation for collective management of protected areas for biodiversity conservation and social inclusion. In: *International Modeling and Simulation Multiconference 2007* (eds F. Barros, C. Frydman, N. Giambiasi & B. Zeigler) pp. 183–8. The Society for Modeling & Simulation International (SCS), Buenos Aires.

Chapin F. S. III, Matson P. A. & Mooney H. A. (2002) *Principles of Terrestrial Ecosystem Ecology*. Springer Science+Business Media, Inc., New York.

Cramer M. (1993) Urban renewal: restoring the vision of Olmsted and Vaux in Central Park's woodland. *Restor. Manag. Notes.* **11,** 106–16.

Da Silva U. S. R. & Silva Matos D. M. (2006) The invasion of *Pteridium aquilinum* and the impoverishment of the seed bank in fire prone areas of Brazilian Atlantic Forest. *Biodivers. Conserv.* **15,** 3035–43.

Drummond J. (1996) The garden in the machine. *Environ. Hist.* **1,** 83–104.

Forman R. T. T. (1995) *Land Mosaics*. Cambridge University Press, New York.

Gotts N. M. (2007) Resilience, panarchy, and world-systems analysis. *Ecol. Soc.* **12,** 24. [Cited 5 October 2010.] Available from URL: http://www.ecologyandsociety.org/vol12/iss1/art24

Gunderson L. H. & Holling C. S. (2002) *Panarchy: Understanding Transformations in Human and Natural Systems*. Island Press, Washington.

Holling C. S. (2001) Understanding the complexity of economic, ecological and social systems. *Ecosystems.* **4,** 390–405.

Hoxit L. R. & Chappell C. F. (1975) NOAA (National Oceanic and Atmospheric Administration) Technical Report. Tornado outbreak of April 3–4, 1974: synoptic analysis. NOAA TR ERL 338-APCL 37.

Johnson, Johnson and Roy, Inc. (1975) Louisville Parks Restoration. Project manual for Louisville Parks restoration. (from Louisville Metro Parks archives).

Kramer C. P., Clare A., Facktor R. D. & Zimmerman P. (1988) Louisville's Olmstedian Legacy: an interpretive analysis and documentary inventory. Louisville Friends of Olmsted Parks. Louisville, KY. (Report in the Louisville Olmsted Parks Conservancy archives).

Levee A. A. (1992) Louisville's Olmsted Park Legacy: selective chronology for Cherokee, Iroqois and Shawnee Parks and the Parkways. (Report in Louisville Olmsted Parks Conservancy archives).

Louisville Olmsted Parks Conservancy (1994) *Master Plan for Louisville's Olmsted Parks and Parkways: A Guide to Renewal and Management*. Louisville Parks Conservancy, Inc., Louisville.

Manning R. (1984) Cherokee Park 10 years later. *The Louisville Times* 27 Mar.

NOAA (National Oceanic and Atmospheric Administration) (1974) Natural Disaster Survey Report 74-1: the Widespread Tornado Outbreak of April 3–4, 1974. [Cited 29

doi:10.1111/j.1442-9993.2010.02237.x

November 2009.] Available from URL: http://www.publicaffairs.noaa.gov/storms/release.html and http://www.publicaffairs.noaa.gov/storms/description.html

Perry E. H. & Samuels T. W. Jr (1998) In praise of Louisville's parks. *The Courier-Journal* 5 Apr.

Pickett S. T. A. & White P. S., eds (1985) *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press, New York.

Rau G. (1975) After the tornado passed: a chronological listing of events pertaining to the cleanup and restoration of tornado damaged park property. (A report prepared by Park Forester Gerry Rau located in the Louisville Metro Parks archives).

Reice S. R. (2005) Ecosystems, disturbance and the impact of sprawl. In: *Nature in Fragments: the Legacy of Sprawl* (eds E. A. Johnson & M. W. Klemens) pp. 90–108. Columbia University Press, New York.

Richardson A. P. (1974) Report of visit for the review of tornado damage in Cherokee Park, George Rogers Clark Park and associated parkways in Louisville, Kentucky, April 17–18, 1974. Report submitted to Louisville Parks and Recreation Department by Olmsted Associates, Inc. Brookline, MA. (In Louisville Metro Parks archives).

Richardson A. P. & Hudak J. G. (1974) Journal of the development of Cherokee Park, Louisville, KY, 1891–1974. Report submitted to the Louisville Parks and Recreation Department by Olmsted Associates, Inc. Brookline, MA. (In Louisville Metro Parks archives).

Rohter L. (2002) Rio Journal: beauties of the sky, filled with hot air and peril. *New York Times* 24 Jun.

Ruitenbeek J. & Cartier C. (2001) The invisible wand: adaptive co-management as an emergent strategy in complex bioeconomic systems. Occasional paper 34. Center for International Forestry Research, Bogor, Indonesia.

Sauer L. J. (1998) *The Once and Future Forest*. Island Press, Washington.

Share A. J. (1976) Restoration of a tornado ravaged park. *Landsc. Arch.* **66,** 456–62.

Silva Matos D. M., Santos C. J. F. & de Chevalier D. R. (2002) Fire and restoration of the largest urban forest of the world in Rio de Janeiro City, Brazil. *Urban Ecosyst.* **6,** 151–61.

Sukopp H. & Starfinger U. (1999) Disturbance in urban ecosystems. In: *Ecosystems of the World. Vol. 16: Ecosystems of Disturbed Ground* (ed. L. Walker) pp. 397–412. Elsevier, New York.

Thomas S. W., Allen A. C. & Deitz R. E., eds (1974) *Tornado! April 3, 1974*. The Courier-Journal and Louisville Times. Louisville, KY.

Walker B. & Meyers J. A. (2004) Thresholds in ecological and social-ecological systems: a developing database. *Ecol. Soc.* **9,** 3. [Cited 5 October 2010.] Available from URL: http//www.ecologyandsociety.org/vol9/iss2/art3

Walker B., Holling C. S., Carpenter S. R. & Kinzig A. (2004) Resilience, adaptability, and transformability in social-ecological systems. *Ecol. Soc.* **9,** 5. [Cited 5 October 2010.] Available from URL: http//www.ecologyandsociety.org/vol9/iss2/art5

Walker B., Gunderson L., Kinzig A., Folke C., Carpenter S. & Schultz L. (2006) A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecol. Soc.* **11,** 13. [Cited 6 October 2010.] Available from URL: http://www.ecologyandsociety.org/vol11/iss1/art13

Zipperer W. C. & Zipperer C. E. (1992) Vegetation response to changes in design intent of an urban park. *Landsc. Urban Plan.* **22,** 1–10.

Zipperer W. C., Foresman T. W., Sisinni S. M. & Pouyat R. V. (1997) Urban tree cover: an ecological perspective. *Urban Ecosyst.* **1,** 229–46.

doi:10.1111/j.1442-9993.2010.02237.x