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ORIGINAL ARTICLE

Community-led reforestation: cultivating the potential of virtuous cycles to confer resilience in disaster disrupted social–ecological systems

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Abstract Human relationships with trees can result in widespread citizen-led reforestation projects that catalyze social–biological-reinforcing feedback loops and set in motion virtuous cycles that restore perturbed social–ecological systems. These virtuous cycles confer resilience in such systems that counterbalance the tendency for vicious cycles to be triggered by destructive behavior and neglect. Given this argument, we ask: how do we cultivate the potential for virtuous cycles to confer resilience in social–ecological systems? To answer this question, we review feedback mechanisms and identify virtuous cycles catalyzed via ecological restoration to highlight their importance to the resilience of social–ecological systems. We then conceptualize these cycles with a causal map (also known as a causal loop diagram) illustrating an example where restoration activities and civic ecology practices contributed to feedbacks and virtuous cycles. Following from this example, we discuss approaches for recognizing and investing in virtuous cycles that accompany social–ecological systems and outline approaches for managing such cycles.

Keywords Disaster · Resilience · Virtuous cycles · Hurricane Katrina · New Orleans · Social–ecological systems

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Introduction

Cycles are recurring series of successive interactions or states, and the City of New Orleans is a city defined by complex interacting cycles. Home to some of the largest collections of mature trees in the world, New Orleans can claim nearly 50 species, including magnolia, pine, live oak, bald cypress (Louisiana's official state tree), and red maple (Goudarzi 2006). Historically trees have held special symbolic significance to residents of New Orleans, contributing to identity and sense of place (Anderson 2004; Boyce 2005; Kearns 2006). Residents returning to New Orleans after Hurricane Katrina struck the city in 2005 shared many stories about the New Orleans landscape before the hurricane, the role that trees played in their lives, how after the storm they used trees as landmarks to find the place where their home once stood, and how the surviving trees gave them hope that they too would persist, would persevere, and would maintain their roots in New Orleans (Tidball 2009, 2013).

The relationship between individuals or communities and trees, especially in symbolic terms, is an important part of individual or community recovery and resilience after a disaster (Tidball 2014). This importance of trees has been associated with sense of place in other hurricane-ravaged cities (Hull 1992) and considered a part of community healing rituals and memorialization in post-9/11 New York City (Tidball et al. 2010). Even when tree planting efforts are ultimately unsuccessful for the trees, the act of coming together as a community for such a shared purpose strengthens the social infrastructure necessary for resilience (Svendsen et al. 2014). Participation in community greening initiatives directly shapes the spatial dimensions of human–environment interactions, fostering an appreciative sense of place (Zia et al. 2014).

Human relationships with trees can result in widespread citizen-led reforestation projects that catalyze social–biological-reinforcing *feedback* loops and set in motion *virtuous cycles* that restore perturbed social–ecological systems. These virtuous cycles may confer resilience in such systems that counterbalance the tendency for *vicious cycles* to be triggered by destructive behavior and neglect. Thus, greater attention to natural elements of a disaster stricken area, and to the acts of interacting with these natural elements, understood via social–biological-reinforcing feedback loops, may further broader efforts to recover from disasters (Tidball and Krasny 2013). Given this argument, we ask: how do we *recognize* and *cultivate* the potential for virtuous cycles to confer resilience in social–ecological systems?

Despite what has been written about larger anthropocentric drivers of ecosystem processes in economic contexts (Hidalgo and Hausmann 2009), including market forces (May et al. 2008), urban planning (Pickett et al. 2004), sprawl (Batty 2008), large-scale watershed degradation (Costanza et al. 2002), and their ultimately negative implications, here, we focus on the role of beneficial human activities, especially urban ecological restoration activities like community forestry or other greening activities, in disaster recovery. These activities, sometimes referred to as civic ecology practices (Tidball and Krasny 2007; Krasny and Tidball 2010, 2012), often emerge when a place is damaged or "broken" (Krasny and Tidball 2014). If, as is so often expected, human activity drives change in urban social–ecological systems (Elmqvist et al. 2008), then it is important to explore how a human activity like urban community forestry might induce virtuous cycles via reinforcing feedback within systems, thereby iteratively contributing to resilience in urban social–ecological systems perturbed by disaster. This premise provides the focus of this paper, sheds light on gaps in current understanding, and gives rise to the question which we raise herein.

To answer the question "how do we recognize and cultivate the potential for virtuous cycles", we review feedback mechanisms and identify virtuous cycles catalyzed via ecological restoration to highlight their importance to the resilience of social–ecological systems. We then conceptualize these cycles with a causal map (also known as a causal loop diagram) illustrating an example where restoration activities and civic ecology practices contributed to feedbacks and virtuous cycles, based upon field work conducted in New Orleans after Hurricane Katrina (Tidball 2012b). Following from this example, we discuss approaches for recognizing and investing in virtuous cycles that accompany social–ecological systems, and outline approaches for managing such cycles.

Feedback loops and related concepts: review and definitions

Although the term "urban ecology" was coined by sociologists who sought to use ecological theory to describe human behavior in the urban setting, researchers are now attempting to integrate human-dominated ecosystems into ecology itself (Collins et al. 2000). Until recently, relatively little ecological research was conducted in urban settings (McIntyre et al. 2000). Ecologists have traditionally sought to understand their subject, the ecosystem, in the absence of humans and generally considered humans chiefly as agents of disturbance (Pickett and McDonnell 1993; Costanza 1996). However, this paper builds on an emerging view (Grove et al. 2015) that humans and the rest of nature continue to interact and form a system with properties and processes that shape urban ecology (Grimm et al. 2000; Elmqvist et al. 2004; Borgstrom et al. 2006; Folke 2006).

In her book *Advances in Urban Ecology*, Alberti (2008) reminds us that when we want to model urban ecosystems, we must "consider the feedback mechanisms that connect the natural and human systems". Specifically, she distinguishes positive (reinforcing) from negative (balancing) feedback mechanisms that operate in urban ecosystems:

> *Feedback mechanisms can be negative, or dampening forms that tend to stabilize systems—such as real estate markets. Feedback can also be positive, accelerating adjustments and leading to unstable conditions that change catastrophically as in the case of ecological succession or the extinction of species.* (p. 231).

The presence of feedback mechanisms akin to the aforementioned in urban systems is alluded to by Grimm et al. (2000) who, while describing their work in urban Long-Term Ecological Research contexts, claimed that "without understanding interactions and feedbacks between human and ecological systems, our view of ecosystem dynamics both at local and global scales will be limited—as will our ability to apply these insights to public policy and land management" (p. 573). Yli-Pelkonen and Niemelä (2005) later remind us, in keeping with resilience thinking, that "biological systems including ecological systems and social systems are open, adaptive systems, which interact with their environments". They go on to argue that "…the importance of feedback for adaptive systems is essential, and these systems can learn from mistakes and self-organize after feedback" (p. 1958). This would seem to be especially important in the case of urban systems perturbed by a disaster.

Social–ecological systems and resilience

The "social–ecological resilience perspective[1]" emerged from a stream of ecology that addressed system dynamics, ecosystem dynamics in particular (Folke 2006). Though human actions have been considered central to the capacity of ecosystems to generate natural resources and ecosystem services for some time, much of mainstream ecology treats human actions as external to the ecosystem. Consequently, human interactions and feedback relationships between ecosystem development and social dynamics have not been adequately explored and analyzed.

Social–ecological resilience refers to the capacity of linked social–ecological systems to absorb disturbances so as to retain essential structures, properties, and feedbacks and continue to develop and innovate (Holling 1973; Walker et al. 2004; Adger et al. 2005). Resilience reflects the degree to which a complex adaptive system is capable of self-organization and building capacity for learning and adaptation (Carpenter et al. 2001; Folke et al. 2002). Here, we view humans as integral to the ecosystem, which shape the system's self-organization. Consequently, ecosystem services in the urban landscape are generated by interacting social–ecological systems and not by ecosystems alone (Niemelä et al. 2011).

It is important to point out here that the term "resilience" can be tricky when applied in disaster contexts, given the term's development through the sciences, humanities, and legal and political spheres. As other authors have noted, as a concept, resilience involves some potentially serious conflicts or contradictions, for example between stability and dynamism, or between dynamic equilibrium (homeostasis) and evolution (Alexander 2013). Although the resilience concept seems to work well within the confines of general systems theory, in situations in which a system formulation inhibits rather than fosters explanation, a different interpretation of the term may be warranted, and as Alexander (Ibid.) rightly points out, this may be the case for disaster risk reduction. Nonetheless, here, we focus on leveraging the rich history of meanings and applications within resilience thinking, while recognizing the dangers or disappointments of relying solely on resilience, broadly, as a model and paradigm.

Given the aforementioned caveat, when thinking about disasters and social–ecological resilience, we concur with the notion that 'all disasters are local', (Ganyard 2009) and as Masten and Obradović (2008) have argued, "all human resilience is local, emerging from the actions of individuals and small groups of people, in relation to each other and powered by the adaptive systems of human life and development". "In the end", as Thomas Campanella says, "the resilience of both cities and enterprises comes down to people" (2006). Masten and Obradović (2008) acknowledge that a variety of systems facilitate human resilience, especially in post-disaster and related contexts, but seem to agree with Longstaff (2005) that those systems are unlikely to be directly available during an unfolding disaster. Their description of these systems includes primarily manufactured ones, such as communication, transportation, manufacturing, and others, and not ecological systems. However, elsewhere Tidball (2012a) as argued for the inclusion in this list of systems that facilitate resilience, especially after a disaster, locally available biological and ecological systems, subsystems, and components, from the smallest to the largest, from the simplest to the most complex. In this sense, one can view disaster as not simply or only an interruption of urban resilience, but rather as a predominant opportunity and catalyst for expression of that resilience.

Feedbacks, virtuous cycles, and systems

Within the general field of systems theory, systems are viewed as the product of components interacting which leads to internally self-organized systems (Holland 1995; Levin 1999, 2005; Folke 2006). Following from the principles of control theory, positive or *reinforcing* feedback amplifies a change to the system, whereas negative or *balancing* feedback counteracts a change to the system. While balancing feedback is implicated in stabilizing or self-regulating system behavior, reinforcing feedback can contribute to a desired (virtuous) or undesired (vicious) transformation of the system. Virtuous modes of reinforcing feedback loops can contribute to the resilience of social–ecological systems (Gallopin 2002; Powell et al. 2002; Matthews and Selman 2006; Selman 2006). On the other hand, the same reinforcing feedback that constitutes a virtuous mode is considered "vicious" if the direction of change in the system is undesirable. Here, we note that the definition of which states are desirable or undesirable is contingent upon the communities affected, for it is they who decide not only *if* a recovery will occur, but what that recovery could or should look like. While exhibiting opposite tendencies for a given definition of desirable, both vicious and virtuous modes of behavior arise from the same fundamental reinforcing feedback mechanism, so that changes in the state of the system amplify or snowball in the same direction with each iteration of the cycle. According to Varis (1999, p. 599), if the direction of influence is negative in relation to a desired system state, such feedback would be considered vicious, and if the influence positively affects the desired state, the feedback mechanism would be considered virtuous. Thus, both the

[1] We are aware of parallel understandings of resilience in the psychological and engineering disciplines, but are here focused on social–ecological resilience.

direction of influence and the subjective interpretation of system behavior affect the identification of virtuous and vicious modes of reinforcing feedback mechanisms.

Feedback loops provide a means to visualize hypotheses of how urban ecological restoration might interact with other processes to help transform a social–ecological system. For example, some urban systems may be characterized as experiencing vicious cycles of poverty leading to crime and environmental degradation, which in turn foreclose economic development opportunities (also referred to as poverty or lock-in traps, cf. Allison and Hobbs 2004). However, it is within these same impoverished neighborhoods that community members sometimes "self-organize" to restore trash- and crime-ridden vacant lots, transforming them into community gardens and pocket parks, which become sites that foster social capital and provide ecosystem services (Bolund and Hunhammar 1999; Barthel et al. 2005; Ernstson et al. 2010a, b). Such civic ecology practices (Tidball and Krasny 2007; Krasny and Tidball 2010, 2012) may be one factor that helps to tip these systems from vicious to virtuous modes.

The notion of feedback in complex systems is frequently employed in climate studies (Rosenfield et al. 2001), such as between vegetation and phosphorus dynamics in tropical dry forest (Lawrence et al. 2007), and in ecosystem resilience studies such as in coastal and seagrass ecosystems (Sunda et al. 2006; van der Heide et al. 2007), earth sustainability (Rockström et al. 2009), and urban ecosystems (Grimm et al. 2000; Grimm and Redman 2004), among others. As Folke notes (2006), social–ecological systems in particular exhibit strong reciprocal feedbacks (Costanza et al. 2001; Gunderson and Holling 2002; Berkes et al. 2003; Janssen et al. 2003; Chapin et al. 2004). These feedbacks and their cross-scale interactions in relation to resilience are relevant when modeling social–ecological systems with multiple stable states (Carpenter et al. 1999; Janssen and Carpenter 1999; Janssen et al. 2000; Carpenter and Brock 2004; Bodin and Norberg 2005).

Feedback is central to social–ecological systems resilience and can be modeled using approaches such as system dynamics. Although useful, heuristic or metaphorical diagrams of information feedback loops with circular causality are incomplete tools for communicating the structure of a complex system and associated model-based insights. As Richardson (1986) points out, causal loop diagrams of feedback loops can blur distinctions between information links and rate-to-level links. As reinforcing loops, virtuous and vicious cycles accelerate both growth and collapse, depending upon the direction of change. These feedback mechanisms are disequilibrating and destabilizing, as described by Holling (1973).

Illustration of virtuous and vicious dynamics

In the above section, we briefly reviewed and defined key systems thinking concepts, such as social–ecological systems and resilience, and feedbacks and cycles that are generally applicable in our disaster case study. In this section, we illustrate these definitions to characterize the dynamics of vicious and virtuous cycles. As stated earlier, cycles are recurring series of successive interactions or states. In ecology, cycling refers to the movement of chemicals or substances through an ecosystem (e.g., nitrogen cycle). Vicious cycles (Gallopin 2002) are produced by reinforcing feedback mechanisms that produce undesirable system states within a landscape (cf. Beisner et al. 2003). A given ecosystem might also contain desirable system states produced by virtuous cycles of people stewarding green space or natural resources, which thus provides greater access to nature and contributes to community and ecosystem well-being (Suutari and Marten 2007; Tidball and Krasny 2008b). Depicted graphically in Fig. 1 as adapted from Walker and Salt (2006), change in a vicious cycle can be imagined with the metaphor of a ball that is constantly swirling around one basin within a landscape, and our goal is to move that ball to a different basin that represents a virtuous cycle and a more desirable state.

To move the ball to a different basin requires either moving the ball itself through making changes within the basin (e.g., increasing the magnitude of the restoration activities) or by changing features of the landscape (see Scheffer et al. 2001; Walker et al. 2004 for a more thorough description of stability landscapes and basins of attraction). For example, we can further envision a "ridge" on the landscape to highlight the bifurcation zone separating the two basins, as illustrated in Fig. 2 and adapted from Walker and Salt (2006). The peak of the ridge represents the bifurcation point, also known as a tipping point, as a threshold of change that enables a shift from the

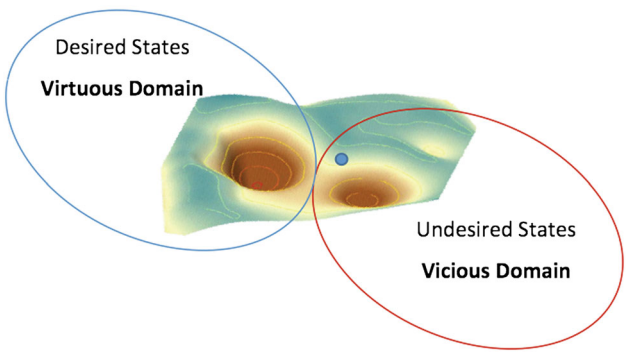

Fig. 1 Stability landscape illustrating virtuous and vicious domains. Adapted from Walker and Salt (2006)

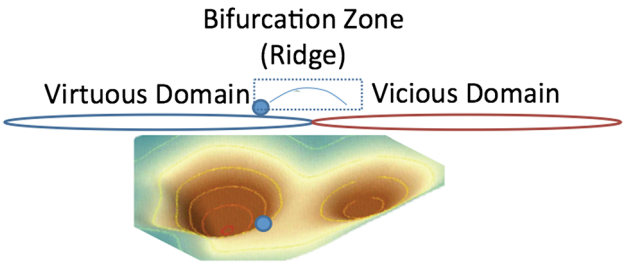

Fig. 2 Bifurcation zone or "ridge" enables tipping between virtuous and vicious domains. Adapted from Walker and Salt (2006)

vicious mode to virtuous mode of behavior or vice versa (Strogatz 1994). In this metaphorical model, the ridge could represent legal or policy barriers, unfavorable public opinion, competition for scarce resources, and so on. In the real world, overcoming the tipping point to cross the ridge might require an influx of resources from outside the vicious cycle, such as an influx of outside money or change in government policy.

Examples of vicious cycles and cascading effects abound in social–ecological systems. Carpenter and colleagues (2006) pointed out how ecological feedbacks may intensify human modifications within ecosystems. We know that ecological change can alter the flow and reliability of the supply of ecosystem services that people receive from nature (Kumar 2010). These ecological changes may, in turn, increase the vulnerability of people and ecosystems to further changes (Cumming et al. 2005; Carpenter et al. 2006). Examples include decreases in coastal area resilience due to removal of large-bodied predators (Jackson et al. 2001), and decreased coastal area resilience leads to increased vulnerability to storms and tsunamis (Adger et al. 2005). As Carpenter and colleagues (2006) note, these kinds of feedbacks and associated cascading changes can cause major shifts in the availability of ecosystem services, which then alter social dynamics in ways that intensify ecosystem change—a vicious cycle.

Examples of virtuous cycles in social–ecological systems are less apparent and less readily available, in part because they represent a counter discourse regarding the role of humans in ecosystems as generally destructive (see Tidball and Stedman 2013 for a full discussion on a counter discourse regarding the role of humans in ecosystems). However, virtuous cycles are produced by the same reinforcing feedback mechanisms that generate vicious cycles, moving in the opposite direction to amplify undesirable system behavior and the associated cascading changes.

The previous work identified virtuous social–ecological feedback loops as the defining characteristic of truly sustainable strategies (Weinstein and Tidball 2007; Tidball and Weinstein 2008, 2011). In scientific terms, a reinforcing, or positive, feedback loop is a phenomenon in which information of the consequences of a behavior or event causes the behavior or event to repeat itself with even greater magnitude.

Figure 3 outlines a set of reinforcing or positive feedback loops that promote social–ecological system resilience when the system changes in the desired direction (the virtuous mode) and that undermine resilience when the system changes in the undesired direction (the vicious mode). Civic ecology practices such as participation in community greening initiatives contribute to both natural and social capital. As illustrated at left in Fig. 3, specific practices such as urban community forestry promote natural capital of the urban forest ecosystem, in turn producing ecosystem services that confer human benefits, building social capital beyond the direct impact of participation in

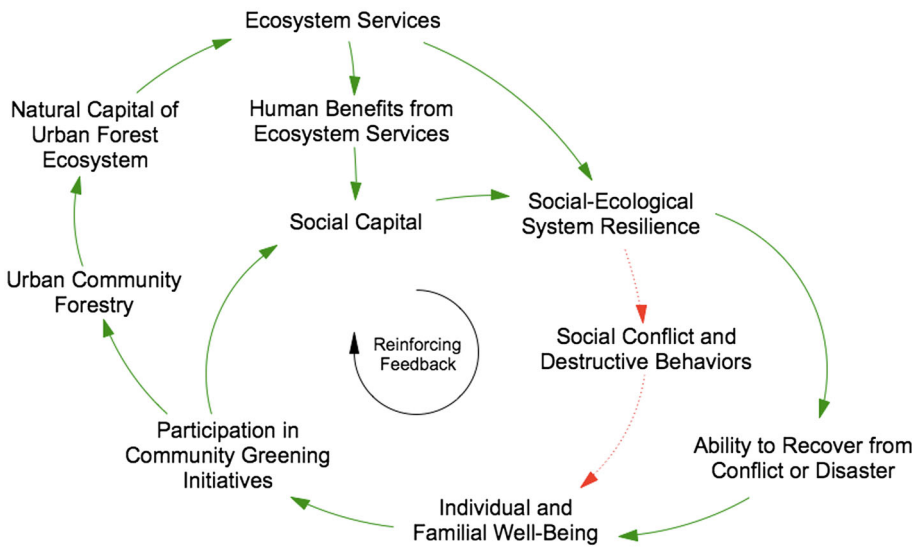

Fig. 3 Reinforcing feedback generating virtuous and vicious cycles of civic ecology practices. Solid green lines indicate positive causal links, whereas dotted red lines indicate negative causal links

community greening initiatives. The cascading effect of ecosystem services, combined with the boost in social capital, adds to social–ecological system resilience.

The negative causal link from such resilience to social conflict and destructive behaviors indicates that it reduces their likelihood. Social conflict and destructive behaviors are seen to reduce individual and familial well-being, so reducing such behaviors through resilience has a net positive impact; in terms of the system, the two negative causal links cancel out, so that the resultant feedback loop is positive or reinforcing. The positive causal link from resilience to the community's ability to recover from a conflict or disaster creates an additional causal pathway to promote individual and familial well-being, creating the conditions for further participation in community greening initiatives.

The virtuous and vicious modes of reinforcing feedback loops are foundational to social–ecological systems' resilience thinking (Gallopin 2002; Powell et al. 2002; Matthews and Selman 2006; Selman 2006; Tidball and Krasny 2011). They represent interactions that are typically self-sustaining and reinforce one another. Thus, identifying virtuous cycles and feedback loops is important, especially in the disaster context, because they are a source of significant change and, therefore, leverage within a system, not only because they are "desirable", "good" or "positive", normatively speaking, in and of themselves.

The operation of virtuous cycles and feedback loops is how movements begin and gain momentum (Weinstein and Tidball 2007; Tidball and Weinstein 2011). Identifying virtuous cycles and feedback loops is particularly important, in the disaster recovery context, because if a social, economic, or ecological system is feeding back information about its progress to itself over time, then it will grow and advance with little help from outsiders. It is not enough to simply identify and locate virtuous cycles and feedback loops. Researchers, policy makers and managers in disaster response and recovery must dig deeper still to identify not just important feedback loops themselves, but the particular *mechanisms* that enable the virtuous behavior of reinforcing feedback loops to operate, whether particularly powerful, charismatic, or well-placed individuals, collective behaviors, institutional forces, or means of information transmission (Tidball and Weinstein 2011).

Given the above description of general, hypothetical virtuous cycles and their importance, what does a "real" virtuous cycle look like, and how can policy makers and managers recognize them when they see them, so that they can invest in them? We will answer both questions using the case of urban reforestation in Post-Katrina New Orleans.

Case study of urban reforestation in post-Katrina New Orleans

The sociologist Kai Erikson (1992) writes that:

> "…One of the crucial tasks of culture… is to help people camouflage the actual risks of the world around them—to help them edit reality in such a way that it seems manageable, to help them edit it in such a way that the dangers pressing in on them from all sides are screened out of their line of vision as they go about their everyday rounds."

Thus, one of the most urgent tasks of disaster recovery and reconstruction is to try to make sense of a disaster to discover or establish meanings that assist in efforts to recover a sense of mastery over both natural and social surroundings (Rozario 2005). Civic ecology practices such as greening often help in this effort of meaning recovery. Poole (1998) invoked the term *civitas oecologie* (civic ecology) to refer to the importance of incorporating sensitivity to both the civic and natural elements of a city in building urban infrastructure. Wolf (2008, p. 308) employs the phrase civic ecology to describe "how people in cities and communities benefit from being involved in environmental projects, how urban ecosystems benefit communities, and how to encourage conservation behavior". In enhancing local ecosystems through such practices as community forestry, community gardening, and watershed restoration, humans also can enhance the social systems nested within larger ecosystems, a kind of resilience enhancing feedback (Tidball and Krasny 2007). Evidence of this was observed through field work conducted in post-Katrina New Orleans (Tidball 2012b).

Human action to restore and steward local ecosystems, and in so doing enhancing social well-being, can and often does occur under the harshest of conditions, including in cities and after disasters such as Hurricane Katrina. Tidball and Krasny (2007, 2010) and Krasny and Tidball (2010, 2014) use the term civic ecology to guide investigations into the system-level and educational implications of the stewardship actions of people in heavily human influenced social–ecological systems, and suggest that attention be paid not only to the outcomes of such practices for people and communities (Wolf 2008) but also to the virtuous cycles and feedback loops created when civically oriented stewardship practices create habitat patches that provide not only social, but also ecological benefits (Elmqvist et al. 2004; Tidball and Krasny 2008a, b).

One example of a virtuous cycle based upon civic ecology practices is seen in the reforestation activities that occurred among citizens in New Orleans after the devastation of Hurricane Katrina in 2005. Hurricane Katrina

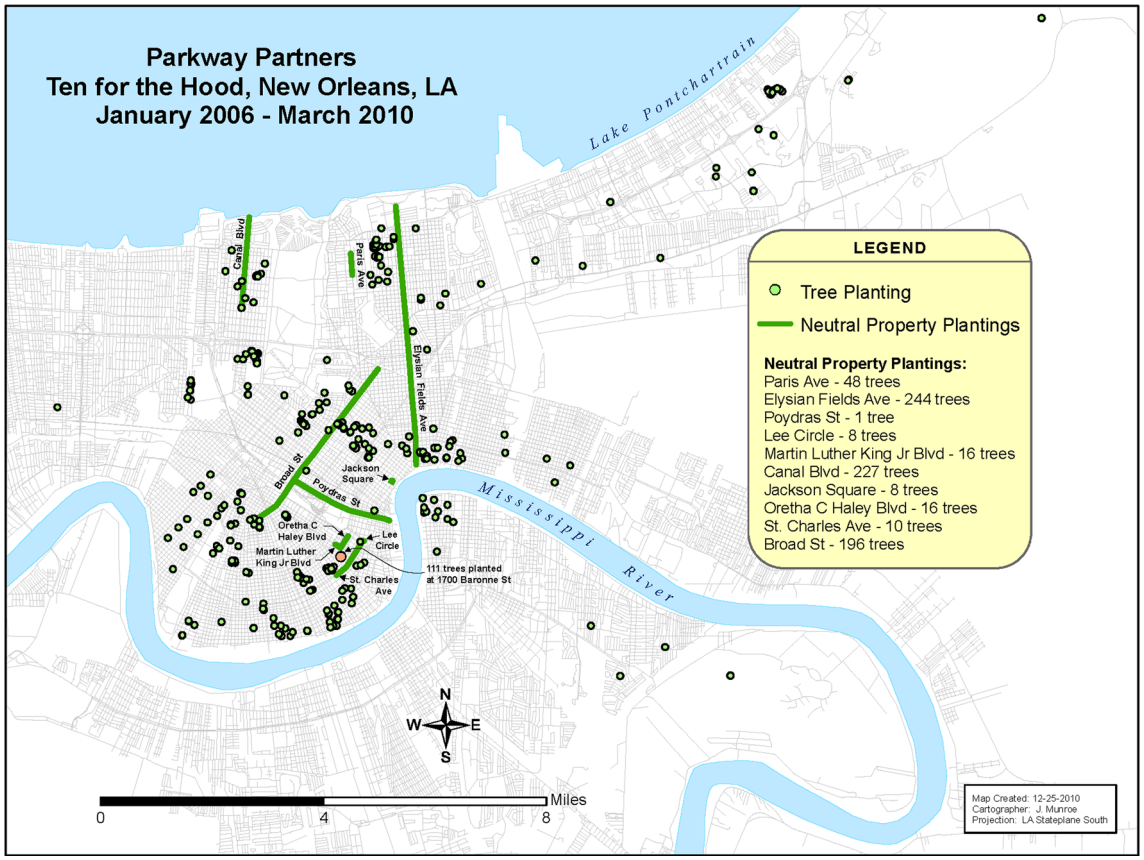

Fig. 4 Map depicting wide dispersal of plantings through the New Orleans Metropolitan area immediately after Hurricane Katrina. Plantings depicted represent only one of many tree planting programs conducted by Parkway Partners. "Neutral property" refers to areas under cultivation that are public right-of-ways

made landfall in New Orleans, Louisiana, USA on August 29th, 2005, devastating the city leaving 1,500 people dead and tens of thousands without homes. Approximately 80% of New Orleans was flooded, with some parts under 15 feet (4.5 m) of water. Most roads and critical infrastructure were rendered inoperable. Mortality and severe structural damage were wrought upon approximately 320 million large trees throughout the Gulf Coast (Chambers et al. 2007), many thousands of which were destroyed in New Orleans. According to Edward Macie, regional urban forester for the US Forest Service's Southern Region, about 75% of the trees in New Orleans were lost due to the storm (Kaufman 2007). The story of New Orleans' struggle to endure weeks of inundation and devastation, and months of disorganized efforts to recover from the disaster, is relatively well known (United States 2006; Waugh 2006; Brunsma et al. 2007). However, the important catalyzing virtuous cycles involving the symbolic roles of trees and the act of tree planting in post-Katrina New Orleans are less widely understood.

Hurricane Katrina's destructive force effectively disturbed and destroyed important elements that contributed to the place-ness of New Orleans (Campanella 2006), and to the individual, familial, neighborhood, and community identities associated with the place, the trees. The loss of such a large portion of the urban forest also had significant biophysical consequences, including disruption to carbon and nitrogen cycles (Chambers et al. 2007), loss of bird habitat, and loss of urban canopy cooling functions (Sheikh 2006; Nowak and Greenfield 2012). Remembering the value of the urban forest of New Orleans in terms of place (Tidball 2014), and less explicitly though palpably in terms of functionality and ecosystem services, many residents began to organize and rally around tree recovery, tree removal, and tree planting (Fig. 4). Not-for-profit organizations as well as academic and extension institutions quickly recognized and responded to the emergence of tree stewardship as a form of symbolic and substantive recovery efforts for New Orleans. Parkway Partners,[2] a non-profit organization whose mission is to "empower residents to improve quality of life through the preservation, maintenance and beautification of "neutral" or public right-of-ways, green spaces, playgrounds, parks, community gardens, and the urban forest in New Orleans", took the lead

[2] http://www.parkwaypartnersnola.org/.

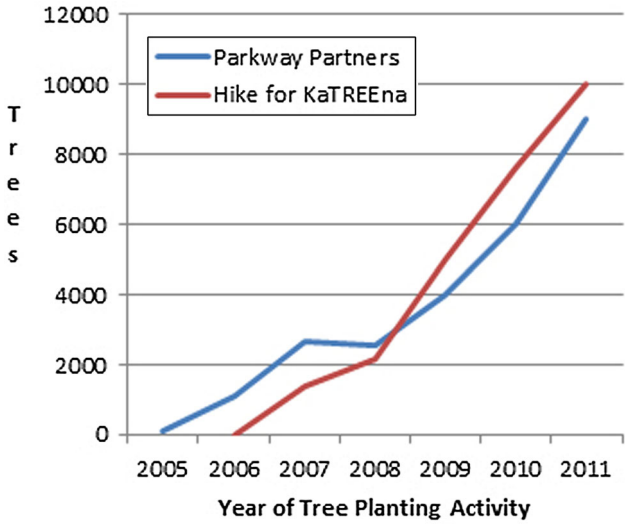

Fig. 5 Graph depicting growth of tree planting activity in New Orleans after Hurricane Katrina as reported by leading NGOs involved in reforestation efforts

in education and action regarding restoration of the urban forest in New Orleans. Through their Tree Troopers planting and stewardship training program involving over 75 citizens, thousands of trees have been planted throughout New Orleans (see Fig. 5). Parkway Partners and the Tree Troopers program trained a number of highly motivated New Orleans residents with deep interest in the importance of the urban forest, including Monique Pilié, founder of Hike for KaTREEna,[3] another not-for-profit organization in New Orleans that has planted thousands of trees in addition to those planted by Parkway Partners (see Fig. 6).

Efforts to document the extent of the urban forest canopy restored by citizen reforestation efforts using spatial analysis including GPS and other techniques have thus far been relatively disappointing, due to the size of most tree specimens used for planting and problems with resolution as well as timing and seasonality of ortho-imagery for comparison (Mornick and Tidball 2010). However, other forms of evidence that citizen led urban reforestation are making an impact on the New Orleans SES are emerging.

Through extensive ethnographic research conducted by Tidball, including semi-structured interviews, participant observation, ritual and symbolic analysis, and participatory visual anthropological methods (See Tidball 2012b for full description of methods for this Ph.D. dissertation field work), it became clear that many New Orleans residents were eager to share stories about how trees figured into their recovery (Tidball and Krasny 2008b; Tidball 2013). Residents recounted many stories about the landscape prior to Katrina, the role that trees played in their lives, how they used trees as landmarks to find the place where their home once stood, and how the surviving trees gave them hope that they too would persevere and maintain their roots in New Orleans. Later, as recovery and rebuilding from Hurricane Katrina progressed, the emergence of a distributed community of practice (Daniel et al. 2003) around urban reforestation was detected (Tidball 2013, pg. 266; Tidball et al. 2010). This urban reforestation distributed community of practice made it their mission to reforest, or "ReLeaf",[4] New Orleans, grounded in both social and ecological motives (Tidball 2013, pg. 266). In short, the New Orleans residents reported that the trees they were planting would serve two kinds of purposes, practical, and symbolic. The practical purposes had to do with ecosystem service provision such as basic aesthetics, shading and cooling, and storm-water management; the symbolic purposes had to do with demonstrations of individual, familial, neighborhood, and New Orleans Metropolitan area–scale resilience, recovery, rebirth, and resistance.

An emergent virtuous cycle involving activities that confer resilience, such as trees and tree planting in New Orleans, was recognized by Tidball in late 2007, after he attended neighborhood meetings and participated in tree planting activities where lengthy discussions ensued regarding the multiple and linked benefits of trees and tree planting in neighborhoods. A depiction of how New Orleans reforestation is theorized to be part of virtuous cycles involving local decisions and local-scale ecological processes that may contribute to large-scale environmental change was later proposed (Tidball and Krasny 2008b). In it, New Orleans citizen reforestation efforts were argued to both (a) foster social system health and resilience (drawing on social capital, civic ecology, and participatory environmental education literatures), and (b) enhance the urban forest or urban ecosystem in measurable ways (drawing on community greening, urban community forestry, and urban restoration ecology literatures). A smaller, virtuous cycle is described wherein more urban community forestry leads to more social system health and resilience, which leads to more urban community forestry and so on. In a larger cycle, the urban forest, newly benefited from urban community forestry activities, produces enhanced ecosystem services, both purely biophysical such as reduced urban heat, increased carbon sequestration, bird and other wildlife habitat, water filtration, storm buffering, and others, as well as aesthetic, cultural, public health-related ecosystem services, resulting in reduced crime (Kuo et al. 1998; Kuo and Sullivan 2001; Branas et al. 2011), improved air (less asthma) and water quality, increased social cohesion, increased economic indicators (Wolf 2003), and other

[3] http://www.hikeforkatreena.org/.

[4] http://www.parkwaypartnersnola.org/ReLeafNewOrleansInitiative.html.

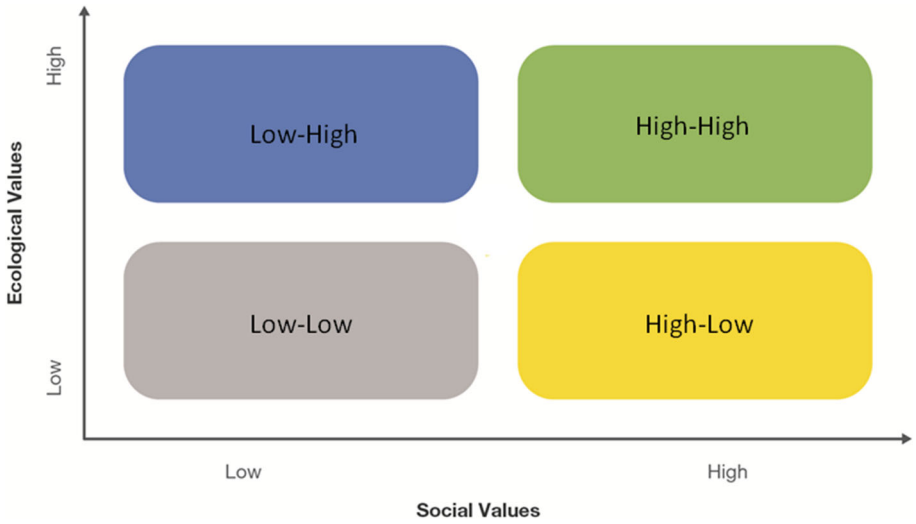

Fig. 6 Social–ecological evaluation matrix, with four quadrants identified as having low–low, high–low, low–high, and high–high social–ecological evaluation rankings (Ranara et al. 2011)

cultural benefits (Miles et al. 1998). These ecosystem services contribute to and enhance social system health and resilience, which may spawn additional urban community forestry and associated positive environmental change.

Discussion—locating feedbacks and virtuous cycles—management implications

Social–ecological matrix

One method that may be useful for detecting the potential for resilience-conferring feedbacks and virtuous cycles is a recently proposed four quadrant social and ecological valuation matrix using combinations of high and low social and ecological values (Ranara et al. 2011). The social–ecological matrix is described as a conceptual framework and tool that complements monetary valuation by capturing non-monetary social and ecological values in human-dominated landscapes. A graphical and intuitive two-axis, four quadrant "possibility space" facilitates thinking about prevailing and desired conditions: geographical areas are identified in a region of interest; their social and ecological values ranked and categorized into the corresponding low–low, high–low, low–high, and high–high value quadrants of the matrix; and the spatial occurrence/distribution of these value combinations is portrayed in a map.

Use of the social–ecological matrix in different contexts can enhance opportunities for greater participation in landscape design and management, stimulating a richer deliberation and investigation of the complex, integrated social–ecological nature of human-dominated systems. Its advantage in cultivating virtuous cycles is in its participatory design. Local residents, school children, or other user groups can be the persons engaged in the initial ranking of a given space, as opposed to only professionals and policy makers. Local determinations of either landscapes to be protected or landscapes to be restored can be communicated in multiple media outlets and fora, contributing to a process earlier mentioned where elements of a system are feeding back information about its progress to itself over time, and then grow and advance with little help from outsiders. As discussed above, simply identifying virtuous modes of reinforcing feedback loops is not enough to set them in motion. Identifying and acting upon the particular *mechanisms* that enable the virtuous cycles to operate are equally important. In the social–ecological matrix, the participatory means of information transmission and resulting civic ecology practices of protection or restoration constitute these facilitating mechanisms.

Six components of a virtuous cycle

A second approach to cultivating virtuous cycles for resilience is an assessment approach that builds on the social–ecological matrix, but differs from it in important ways. In the matrix above, the "sweet spot" is in the "high–high" quadrant. As such, the matrix approach may be limited to accentuating landscape properties or characteristics, with an eye towards planning and restoration activities or objectives. To better identify particular feedback loops of virtuous cycles that confer resilience requires a different approach, one that better characterizes social–ecological processes.

Referring back to the reinforcing feedback diagram (Fig. 3), five elements comprise the feedback that primes the cycle to "repeat and expand" in a virtuous or vicious direction. In Table 1 below, we articulate five elements that are necessary variables for social–ecological virtuous cycles. Table 1 contrasts both virtuous and vicious aspects of each

Table 1 Elements of reinforcing feedback cycle with virtuous and vicious aspects pertaining to civic ecology practices (CEP)

Element of cycle	Virtuous aspects	Vicious aspects
1. Participation in community greening initiatives	Emergence of CEP promotes participation in community greening initiatives	Absence of CEP deters participation in community greening initiatives
2. Natural capital of urban forest ecosystem	CEP increases the ecosystem stocks that produce valuable goods	Lack of CEP depletes the ecosystem stocks that produce valuable goods
3. Ecosystem services	Increase in services that benefit people like shade and aesthetics	Decline in ecosystem services that benefit people
4. Social capital	Increase in social interaction and places for social engagement	Decrease in social interaction and absence of places for social engagement
5. Individual and familial well-being	Increase in self-satisfaction, reward, and well-being	Diminished self-satisfaction, reward, and well-being
6. Reinforcing feedback mechanism	Recurring engagement through social connectivity, inertia, and/or momentum	Obstacles to engagement persist and include social isolation

element. The sixth element in Table 1 is the operation of the feedback mechanism. For a virtuous cycle to be reinforced, there must be connectivity and inertia or momentum that can be relatively easily understood and visualized.

As posited above and outlined in Table 1, we argue that there are six important elements that constitute a virtuous cycle that confers resilience in social–ecological systems. Each of these elements builds upon research spanning multiple disciplines. The six elements are further described below.

Element 1—emergent civic ecology practice

Holling and Gunderson's (2002) adaptive cycle represents a useful metaphor for how a social–ecological system changes over time, with a period of rapid growth followed by a conservation phase, eventually leading to brittleness or reduced ability to absorb shocks or disturbance. Thresholds are reached when disturbance forces the system into a new state characterized by different processes. Although initially chaotic, such drastic change and "energy release" also provide opportunities for reorganization and rebuilding. It is during this release phase, whether following war, disasters, or the collapse of political entities and institutions, that civic ecology practices often emerge and contribute to the subsequent reorganization phase (Krasny and Tidball 2012), such as community gardening in post-conflict Bosnia, the creation of Martissant Park in Port-au-Prince, or the greening of the Berlin Wall Trail.

Element 2—civic ecology practices increase natural capital

Civic ecology practices often occur in or encompass parks, community gardens, and other green infrastructure, which serve as sites for wastewater treatment, microclimate regulation, pollination, food production, education, and recreation (Bolund and Hunhammar 1999; Colding et al. 2006; Dearborn and Kark 2009; Barthel et al. 2010; Ernstson et al. 2010a; Niemelä et al. 2011). Civic ecology practices (Tidball and Krasny 2007) including community tree planting in post-Katrina New Orleans (Tidball and Krasny 2008a, b; Tidball 2014), natural area restoration near Cape Town (Ernstson et al. 2010b), and oyster restoration in NYC (Krasny et al. 2014) contribute to the green infrastructure in many cities, which result in net increases in natural capital, such as trees, urban and suburban terrestrial ecosystems, and the atmosphere.

Element 3—natural capital increases production of ecosystem services

Costanza and colleagues consider the general class of natural capital as essential to human welfare, and link stocks of natural capital to provision and production of ecosystem services (Costanza et al. 1997b). Natural capital captures solar energy and behaves as an autonomous complex system, and contributes to the production of marketed economic goods and services, which are linked to human welfare. Natural capital also produces ecological services and amenities that directly contribute to human welfare without ever passing through markets (Costanza 2000). We argue here that efforts to conserve or better yet, increase stocks of natural capital are explicitly linked, especially in already constrained urban or heavily populated landscapes, to production of ecosystem services (TEEB 2010). Quite simply, in the case of urban reforestation, increasing natural capital stocks by planting more trees to expand the urban forest results in potentially greater production of ecosystem services.

Element 4—access to benefits of ecosystem services increases social capital

In addition to natural capital, scholars of ecological economics and others have identified human, manufactured, and social capital as important to human well-being (Costanza et al. 1997a, b). In the domain of social capital, we inevitably must contend with the complex, controversial, and continually evolving concept of human well-being (Butler et al. 2003; Balmford et al. 2005; Butler and Oluoch-Kosura 2006). As Butler and colleagues argue, "even though some of the main elements of human well-being (including the feeling of security) can be considered psychological, these psychological aspects are shaped by and reflect material circumstances, including *access to adequate ecosystem services* (emphasis added)… in many cases, an insufficiency or maldistribution of ecosystem services contributes to a sense of insecurity, and often, to poor social relations" (Butler and Oluoch-Kosura 2006). We understand such insecurities and poor social relations in social capital terms, and find the linkage easily discernible between access and benefits of ecosystem services and social capital.

Element 5—civic ecology practices increase well-being

In addition to social–ecological memories (Barthel et al. 2010; Nykvist and von Heland 2014) of horticultural practices, less tangible, evolutionary memories of human's relationship to nature may come into play (Tidball 2012a). Kellert and Wilson's (Wilson 1984; Kellert and Wilson 1993) notion of biophilia, i.e., "the connections that human beings subconsciously seek with the rest of life", is useful in understanding human's need for, and the benefits they derive from, being in and caring for nature. Louv's (2006) *Nature Deficit Disorder* synthesized several decades of research on the emotional, psychological, and cognitive outcomes of time spent in nature; a much smaller body of research has addressed the benefits of active nature stewardship (e.g., Austin and Kaplan 2003).

Element 6—connectivity, inertia, and momentum: is it a cycle?

This element entails determining if a perceived effect or change in a social–ecological system is an isolated incident, or if it is "catching on" and spreading throughout a population. Explanations for dissemination, adoption, and adaptation of ideas and practices come from many disciplines and fields including innovation/adoption (Rogers 1995), social network analysis (Bodin and Crona 2009), social innovations (Moore and Westley 2011), and policy entrepreneurs (Maguire et al. 2004). Specific to systems thinking and feedbacks are descriptions of connectivity, inertia, and momentum from expansive cycles (cf. Engeström 1987; Barab and Roth 2006; Chawla 2008), swarm theory or swarm intelligence (cf. Bonabeau et al. 1999; Karaboga and Akay 2009), collective action (Olson 1971; Udehn 1993), social movements' theory (Jamison et al. 1989; Melucci 1992), and so on. A virtuous cycle might demonstrate connectivity, inertia, or momentum in any of the above ways or in ways not yet uncovered.

A tool for cultivating virtuous cycles?

Given the conceptual framework outlined above, how might planners, practitioners, and scholars actually go about detecting and then cultivating desirable virtuous cycles? Here, we introduce what we hope will be an ongoing, collaborative, iterative construction of a tool for evaluating whether or not a given system possesses or shows potential for emergent civic ecology practices that catalyze or initiate resilience-conferring virtuous cycles. One might use the chart below to assess a social–ecological system wherein civic ecology practices might possibly be expected to contribute to the emergence of virtuous cycles. The following paragraphs walk the reader through an illustrative exercise to simulate detecting and cultivating virtuous cycles using New Orleans post-Katrina (or other high-profile cases) as an example.

As above, the first step is to locate the emergence or self-organizing element: does the system possess or show potential to possess emergent civic ecology practice? In the case of post-Katrina New Orleans, emergence presented through city residents who organized around social–ecological memories (Barthel et al. 2010, 2013; Tidball et al. 2010) involving the importance of trees to identity and sense-of-place, and engaged in civic environmental stewardship practices to deal with grief as well as to counter narratives about the failure of New Orleans as a city and predictions of its demise (Tidball 2014). In New York City, after 9/11 citizens similarly engaged in self-organized greening activities to memorialize those lost to the terrorist attacks, and to demonstrate solidarity in their time of grieving (Tidball et al. 2010). After a 2011 tornado destroyed over 2000 buildings in Joplin, Missouri, and took the lives of 160 town residents, civic ecology practices began to emerge almost immediately as townspeople created Facebook pages and used other social media to organize themselves to plant trees and use tree memorialization as an immediate salve to their wounds. And in Detroit and other "rust belt" great lakes cities such as Chicago and Cleveland (Hansen 2008), virtuous cycles of self-organized greening activity begun in the aftermath of

Table 2 Diagnostic tool for detecting virtuous cycles via civic ecology practices (CEP) in social–ecological systems

Diagnostic question	Yes, no, don't know?	Examples or description
1. Does the system possess or show potential to possess emergent civic ecology practice?		
2. Is there evidence of CEP increasing stock of ecosystem goods into the future?		
3. Is there evidence of CEP increasing ecosystem services?		
4. Is there evidence of CEP increasing social interaction and engagement?		
5. Is there evidence of CEP increasing individual or familial well-being?		
6. Are there examples of connectivity, inertia, and momentum generated through CEP?		

the devastating Dutch Elm disease outbreaks in the Midwest have continued to repeat and expand, and can now be seen to be powerful movements in opposition to erosion of their respective cities' stature (cf. Chicago Wilderness[5] or Greening of Detroit[6]). Many other examples from the US and abroad illustrate the emergence or self-organizing first element. These examples shed light upon how the system possesses or shows potential to possess emergent civic environmental stewardship practices.

After detecting an emergent, self-organizing civic environmental stewardship process within a system, the second step is to ascertain if there is evidence of civic ecology practices that measurably increase the stock of ecosystem goods into the future. In New Orleans after a significant damage to the urban tree canopy as a result of Hurricane Katrina, civic ecology practitioners engaged in large-scale tree planting (see Fig. 6) that increased the stock of ecosystem goods the trees and urban forest represent. Therefore, a policy maker using the diagnostic tool (see Table 2, above) above would easily be able to answer yes in the second column in this case, and then describe the increase in stock of ecosystem goods.

Similar to step two above, the third step is to ascertain if there is evidence of civic ecology practices increasing quality and/or quantity of ecosystem services. Presumably, if ecosystem goods are being produced by civic ecology practices, then it is likely ecosystem services are being produced as well. However, it is important to distinguish between the two, and to be specific about the particular ecosystem services being produced, so that the virtuous cycle diagram that results accurately reflects what is occurring in the system of interest. In New Orleans, there were a number of ecosystem services attributed to increased stocks of ecosystem goods derived from reforestation activities; aesthetic, provisioning, and regulating. One can imagine multiple possible iterations of virtuous cycles being diagramed specifically addressing individual ecosystem services and implications of increases in their quantity or quality.

Step four requires the evaluator to integrate across other steps by inquiring as to evidence of civic ecology practices increasing social interaction and engagement. Though, as discussed above, one might potentially identify multiple possible iterations of virtuous cycles being diagramed specifically addressing individual ecosystem services, some will be more obviously related to social interaction and engagement then others. Though more trees in New Orleans meant better storm-water retention, that service was not mentioned as important to social interaction and engagement, where beautification and restoring a sense of place were mentioned repeatedly as ecosystem services that could easily be seen as linked to social interaction and engagement via tree planting parties and events, tree planting and tree care training sessions, and so on.

After accounting for benefits in terms of natural capital, ecosystem services, and social capital, the fifth step is defined via the concepts of individual and family well-being that arise from and reflect aspects of social–ecological system resilience; does participation in civic ecology practice increase feelings of personal self-satisfaction, reward, and well-being? For the case of New Orleans, resident involvement in the self-organizing and expanding community of practice emerging around reforestation of the city after hurricane Katrina contributed to increased stocks of social capital, and of individual- and family-level safety, security, and well-being (Tidball 2014). Similarly, in Galveston, Texas, which suffered a devastating hurricane in September of 2008, greening advocates worked towards rebuilding "avenues of majestic trees of the future interspersed with the art forms of the lost trees in the shapes of sculptured angels, birds, dogs, tin men, mermaids, and geishas.[7]" These kinds of emergent re-greening and recovery efforts are reported to significantly enhance individual and family well-being (Campbell and Wiesen 2009).

After determining whether or not participation in civic ecology practice increases feelings of personal self-satisfaction, reward, and well-being in the particular system of interest, the sixth step is to consider how the feedback cycle operates. This final step is likely the most

[5] http://www.chicagowilderness.org/.

[6] http://greeningofdetroit.com/.

[7] http://theislandermagazine.com/?p=2441.

idiosyncratic and context-specific, and, therefore, most challenging. The challenge is to discover and document examples of connectivity, inertia, and momentum generated through civic ecology practices. In New Orleans, as more and more residents felt the positive morale in their neighborhoods increasing as a result of the virtuous cycle associated with the civic ecology practice of reforestation of the city, they began to share their stories with others, who would then decide that they wanted to be involved. News media then began to report on these "feel good" stories, which became more and more numerous as time went on, priming the cycle to expand and repeat anew. Tree planting then shifted from small-scale neighborhood recovery and morale boosting, to a wide-scale phenomena or movement promulgating a hopeful "rebirth" counter discourse to the stories of New Orleans as a so-called "resilience failure" (Westrum 2006).

Downsides, issues of efficacy, and other areas for future work

A few questions emerge as a result of necessarily applying a critical lens to the proposed framework and the case within which it is situated. For example, a fair question is "what are the *downsides* to investment in the urban forest in New Orleans? This question takes into consideration the potential undesirability (to some) of greening leading to gentrification and displacement (Wolch et al. 2014), possible unintended ecosystem disservices (Lyytimäki and Sipilä 2009), and so on. The question would then be, would we detect these "vicious cycles" using the approach described above? This requires further inquiry.

Another set of question emerges when we consider the fact that the cycle(s) we describe related to community reforestation occurs alongside, in parallel with, and nested among other cycles, such as of real estate investment or disinvestment such as has occurred in some neighborhoods in New Orleans after Katrina (Groen and Polivka 2010); where might we see interactions with other components of the social–ecological system? And when might those interaction effects "drown out" some of the aspects of the virtuous cycles identified? These, too, require further analysis, but are likely beyond the scope of this initial approach.

Finally, questions emerge regarding counter cases and counter actions. When *don't* we see emergence of civic ecology practices and the development of virtuous cycles, and why? When *don't* civic ecology practices enhance well-being? When *don't* they enhance natural capital? These are important questions, ones that we hope situate this article as a first step towards answering, yet for now, are still unanswered (but see Tidball and Lee 2017 for a case where Civic Ecology practices were expected to emerge, but did not).

Conclusions

This study was motivated by the case of New Orleans and the importance its residents placed upon trees in terms of their symbolic significance and their contribution to a sense of place. Residents returning to New Orleans after the 2005 hurricane recalled and acted upon relationships between people and trees as important components of recovery and resilience. We reviewed the concept of feedbacks and highlighted their importance to resilience of social–ecological systems, and developed a conceptual framework for exploring virtuous cycles that are catalyzed via social–ecological restoration.

The framework developed in this paper contributes to the conceptualization of the six components of a virtuous cycle that can provide an assessment tool for detecting, locating, and if possible cultivating virtuous cycles and resilience-conferring feedbacks. These concepts are derived from the first author's field work in New Orleans. Future research will test these ideas in different contexts to determine whether virtuous cycles are similar in terms of the six elements described. This approach to the characterization of virtuous cycles offers much promise in managing for resilience, especially in disturbed systems.

Symbolic relationships with trees can result in beneficial human activities such as widespread citizen-led reforestation projects, catalyze reinforcing social–biological feedback mechanisms, and set in motion *virtuous cycles* in perturbed social–ecological systems that confer resilience. Cycles in systems start by some action that pushes a recurring series of steps and interactions. Hurricane Katrina crossed a threshold beyond which the potential transition into a vicious mode that emphasized degradation of the environment was possible. We can think of this as an undesirable basin of attraction as depicted in Figs. 1 and 2. However, investment in tree planting moved the system across the same threshold to start the transition to a virtuous mode that reversed the fixation on human losses and instead emphasized rebuilding and rebirth of the community and the social–ecological system. Two main challenges for widespread application of this finding are, first, to better understand the process involved in breaking one mode and triggering another, and second, to learn how to influence a system to move beyond a threshold to desirable basins of attractions rather than undesirable ones. Once the virtuous mode of a reinforcing feedback loop is enabled, the task is to keep it going in a desirable direction. The example of New Orleans' recovery underscores this point: initial investment and human interactions that are positive,

rewarding, and reinforcing can lead to important virtuous social–ecological feedbacks system wide.

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