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Ecological integrity in urban forests

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Abstract Ecological integrity has been an umbrella concept guiding ecosystem management for several decades. Though plenty of definitions of ecological integrity exist, the concept is best understood through related concepts, chiefly, ecosystem health, biodiversity, native species, stressors, resilience and self-maintenance. Discussions on how ecological integrity may be relevant to complex human-nature ecosystems, besides those set aside for conservation, are growing in number. In the case of urban forests, no significant effort has yet been made to address the holistic concept of ecological integrity for the urban forest system. Preliminary connections between goals such as increasing tree health, maintaining canopy cover, and reducing anthropogenic stressors and the general notion of integrity exist. However, other related concepts, such as increasing biodiversity, the planting of native species, and the full meaning of ecosystem health beyond merely tree health have not been addressed profoundly as contributors to urban forest integrity. Meanwhile, other concepts such as resilience to change and self-maintenance are not addressed explicitly. In this paper we reveal two camps of interpretation of ecological integrity for urban forests that in turn rely on a particular definition of the urban forest ecosystem and a set of urban forest values. Convergence and integration of these values is necessary to bring a constructive frame of interpretation of ecological integrity to guide urban forest management into the future.

Keywords Urban forests · Ecological integrity · Urban forest management

Introduction

The application of ecological principles and concepts to urban ecosystems is becoming more relevant every day (Niemelä et al. 2011). With a predominantly urban population (UN-HABITAT 2010), many people's experiences with nature are limited to urban nature.

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However, ecological principles and concepts are difficult to apply to ecosystems in an urban setting. A key ecological concept and a shared principle in ecosystem management is that of ecological integrity.

The concern here is the urban forest, a dominant feature of many cities. Though nobody has been explicit about urban forest ecological integrity in the literature, connections between issues of urban forest functions, diversity, and stressors have been made, which in turn evoke the broader notion of integrity. The purpose of this paper is to bring together these fragmented ideas and give meaning to the concept of ecological integrity as it applies to the urban forest, and begin giving a more clear understanding of what an ecologically sound and sustainable management of the urban forest is really about.

The paper begins with a general discussion of ecological integrity and a definition of the urban forest. The third section goes into detail about ecological integrity concepts and their application in the urban forest context, chiefly: ecosystem health, biodiversity, native species, stressors, resilience, and self-maintenance. We then analyze the existing frames of interpretation of urban forest ecological integrity and discuss how to bring about a broader and deeper conceptualization of what urban forest ecological integrity may mean based on our understanding of ecological functions, biodiversity, native species, stressors, resilience and the self-maintenance of socio-ecological systems.

Ecological integrity

In its broadest definition, ecological integrity refers to the wholeness and proper functioning of an ecosystem (Angermeier and Karr 1994). This general notion refers to two aspects of ecosystems: their structure, i.e. species and communities (Noss 1990), and the function, or natural processes (Karr 1992). Many operational definitions of ecological integrity for conservation area management in North America call for maintaining the natural, wild, pristine elements of an ecosystem that are not interfered with by human influences (e.g. Parks Canada 2005).

Ideally, this definition should apply to all ecosystems. However, scholarly debate about ecological integrity's objectivity and, thus, its wide range of applications, is divergent. This is mainly because the concept is underlined by philosophical notions on the ontology of nature and epistemology of science. For example, while many cite how ecological integrity is a guiding principle for the management of pristine ecosystems, the notion of integrity is ignored when referring to human-nature ecosystems, such as cities and agricultural landscapes (e.g. Alberti et al. 2003). Moreover, developing quantitative indicators of ecological integrity for natural ecosystems has been an important task. For instance, for forests a wide range of measures from net primary productivity to deadwood material determine its integrity (see LaPaix et al. 2009). Though measurability adds objectivity to the concept (Noss 1995), our selection of measures is essentially based upon assumptions about the ideal behaviour of an ecosystem (Kay 1993), which in turn encompasses a set of normative scientific statements that standardize nature. Many see this ought-to-be paradigm as proof that our interpretation of ecological integrity has less to do with natural reality, which is dynamic given a long-enough time frame, and more to do with value-laden postures about what we consider important in nature (Turner and Beazley 2004).

Revealing values in the meaning of ecological integrity reflects that there is dynamism, uncertainty and complexity in the concept (Kay and Regier 2000). Opponents to this idea fear that it presents ecology as a belief system rather than a science (Lackey 2001). The inclusion of a human values discourse in ecological science may seem like a humanization of ecology, which fosters speciesism and unethical assumptions. However, others argue that an ecologization of humanity is ethically necessary to preserve valued life-sustaining structures and/or processes (Westra 1994). Ecological concepts should avoid becoming advocacy calls for prioritizing either nature above humanity or humans above nature (Latour 1998). Any constructive interpretation of ecological integrity requires a constant revision of our own biases (Steedman and Haider 1993; Miller 2000). If stripped of its values, the notion of integrity becomes invalid as a tool for ecosystem management. Rather than a divergent notion, our conceptualization of integrity is attached to a broader socio-ecological model, where ecosystem management can be based on the way we understand nature and the values we attach to it (Moffatt and Kohler 2008). After all, any interpretation of ecological integrity should give us a perspective on how to manage ecosystems by bringing humans and nature more closely together (Westra 2008).

Under this new values-based theoretical platform, ecological integrity, as a tool for management, can be applied to non-pristine natural environments. Some authors have applied ecological concepts to the urban forest before (e.g. Savard et al. 2000), but the concept of ecological integrity remains unexplored in its entirety. We set out to review how ecological integrity is understood for the urban forest. This work is facilitated by exploring the concept through other associated and narrower concepts. The concepts discussed here, and that have been previously recognized in the literature, are those of ecosystem health, biodiversity, native and invasive species, and anthropogenic stressors (Freedman et al. 1995), and ecosystem resilience and self-maintenance (Crabbé and Manno 2008). However, it is pertinent first to explore our conceptual model of the urban forest.

The urban forest

There is a widely accepted definition that the urban forest is all the trees in urban areas, whether they are natural or planted (Rowntree 1984). From an ecological point of view, this definition is limited. As an ecosystem, the urban forest encompasses associated elements such as animals and the general physical environment, such as the soil and atmosphere. An urban forest may be defined against the backdrop of a natural forest, with its structural and functional components. The urban forest structure refers to the biophysical and geographical characteristics of the ecosystem, that is, its species composition, diversity, age classes and health status, as well as to the arrangement of forest elements in relation to each other and to non-living urban infrastructure. By urban forest functions, we refer broadly to the physical processes that influence nature and/or people (de Groot et al. 2002), such as carbon capture, soil quality regulation, and wildlife associations.

Following the ideas of the earlier section, the selection of such structural and functional components depends on how an urban forest is valued. Beyond any moral characterization, an urban forest value is defined as whatever we consider important in relation to the urban forest (Ordonez and Duinker 2010). Values in relation to ecosystems, such as forests, can be intrinsic (i.e. for themselves) or assigned (for the benefit of people) (Bengston and Xu 1995). Urban forest values may be fruitfully classified into environmental, ecological, social and economic categories, including air pollution removal (Nowak et al. 2006), wildlife connections (Adams 2005), positive psychological effects (Ulrich 1999), and many others. Urban forest structure, function, and values are concepts that help us enormously in determining how the broad idea of ecological integrity applies to this particular ecosystem type.

Because the urban forest has a differentiated structure, with a diverse composition of size, species diversity and composition (e.g. Dorney et al. 1984), there is an ecological specificity to the different scales at which the urban forest occurs. With such variations, only some ecological processes and structures may apply at one time. Because of this, difference and variability, some ecological concepts are difficult to apply to the urban forest. This is no different with the concept of ecological integrity, as we shall see below.

Ecological integrity concepts and urban forest ecosystems

Ecosystem health

The notion that an ecosystem retains its integrity if it remains healthy is straightforward. Ecosystem health is a metaphor that serves to explain how an ecosystem should function (Costanza et al. 1992), and it mainly implies that the natural processes in the ecosystem, such as nutrient recycling, are maintained (Karr 1996).

A discussion of which ecological functions are to be maintained and at what level or rate is then needed. The kinds of ecological functions necessary for forest ecosystem maintenance vary from the very basic to the specific, that is, from net primary productivity to provision of food and shelter to particular native animals (Kohm and Franklin 1997). Many ecological functions between hinterland and urban forests are not the same. Some of these functions are explored in Table 1. Under an ecological lens, a typical urban forest seems devoid of integrity because specific ecological processes are not at natural levels (McDonnell et al. 1997).

A case for the naturalization of urban forest processes then seems to guarantee good forest health. This may involve increasing forest patch size, as many ecological processes are most significant in large and continuous forest stands (Zipperer et al. 1997), and planting

Table 1 Ecological functions of the urban forest and their qualities

Function	Characteristics In The Urban Forest	Example Reference
Nutrient & carbon cycling	Nitrogen levels in urban soils are high due to fertilizers and higher temperatures. Tree contribution to these cycles is minimized by direct removal of organic matter.	(Pouyat et al. 1997)
Seed dispersal & succession	Generally, almost non-existent (except unmanaged areas). Depends on forest patch size. Dominated by non-native species.	(Heckmann et al. 2008) (Kostel-Hughes et al. 1998)
Wildlife associations	Depends on forest patch size and the species. Generally, associations are few and species are homogenized.	(McKinney 2006)
Atmospheric regulation	Trees regulate atmospheric pollutants through dry deposition.	(Nowak et al. 2006)
Microclimate regulation	Trees regulate microclimate through transpiration, shade, heat insulation, etc.	(Heidt and Neef 2008)
Carbon emission regulation	Trees regulate carbon dioxide emissions by direct capture and reduced energy use.	(Nowak and Crane 2002)
Hydrological cycles regulation	Trees regulate hydrological cycles via water uptake, shielding and transpiration	(Girling and Kellett 2002)

native species. From this viewpoint, achieving health is determined by structural alterations, such as the size of tree stands and native species content of flora and fauna, which in turn serve to support native species content of flora and fauna and reduce the size of the built environment.

However, from a strictly functional perspective, many argue the opposite. Many ecosystem functions can be maintained and even enhanced with different structures of non-native species (Kendle and Rose 2000). More profoundly, the environmental conditions of an urban forest are determined by functions such as atmospheric regulation, which in turn contribute to human health. In fact, most of the urban forest literature is concerned with environmental functions such as air pollution removal, carbon storage and climate amelioration, among others (e.g. Oleyar et al. 2008; see also Table 1). Because some of these functions of the urban forest occur at the scale of individual trees, the notion of health has been reduced to keeping individual trees healthy (e.g. Dwyer et al. 2003). This can be achieved by purely techno-ecological approaches such as pruning, planting standards, structural soils, artificial fertilizers, etc. This approach relies also on measures of good functioning of an urban forest such as canopy-cover percentages. This indicator of urban forest health finds its way into many urban forest management plans across North America (e.g. SeattleGov 2007; City of Oakville 2008).

The concern about ecosystem functions in the literature has led the concept of health to be tied inextricably to environmental issues and to human health (Tzoulas et al. 2007). Other ecological functions, such as seed dispersal, succession, and wildlife support, are not addressed in this interpretation. Whereas ecosystem health could be seen under a strict functional lens, it does not, by itself, illustrate the full meaning of ecological integrity if ecological functions are narrowly determined and many structural components are ignored. These structural issues are mostly associated with biodiversity and native species, as discussed below.

Biodiversity

A biodiverse ecosystem, that is, one that maintains a particular natural composition and assemblage of species, habitats and genes (Angermeier and Karr 1994), is deemed to have integrity. At the species level, biodiversity can be structural or functional. Structurally, biodiverse ecosystems resist diseases and species invasions. Some claim that a maximum representation of a single tree species in the urban forest of 15 % is appropriate (e.g. Miller and Miller 1991) to counteract threats such as the emerald ash borer (Poland and McCullough 2006). However, isolating this sole purpose of biodiversity also means that non-native plantings can also make the urban forest resistant (Muller and Bornstein 2010), as they still enhance biodiversity as long as they are not invasive (Alvey 2006). After all, different permutations of biodiversity can be achieved with different assemblages of species and ecosystems (Angermeier 1994).

Functionally, biodiversity arguments focus on native diversity. Native vegetation prevents invasive species threats (Lyons and Schwartz 2001) and homogenization (McKinney 2006) because of its efficient use of resources that prevents other species from taking hold (Vitousek and Hooper 1993). While this is certainly true if species belong to particular functional groups (Tilman et al. 1997), an artificial mix of species may optimize certain functions, as with the case of resistance to diseases and pests. Yet, artificial mixes of species mean that other functions, such as specialist and rare-species connections, are lost. This is a concern because while generalist species (i.e. those with an ample ecological niche) can make the best of a highly stressed ecosystem, specialized and/or rare species (i.e. those with a narrower ecological niche) cannot. While the most basic functions of an ecosystem can be maintained by generalist and even non-native species, the inability of the ecosystem to support specialist or rare species reflects a lack of integrity (McKinney 2002), since certain structural components of urban forest ecosystems are lost in this way.

Nonetheless, the idea that urban forests cannot support native and rare species because of unnatural conditions is relative. Landscape transformations in the hinterland make some urban areas suitable for native and rare species (e.g. Godefroid and Koedam 2003; Stewart et al. 2004). Moreover, at the habitat level, the new habitats created by urban transformation are diverse (Rudd et al. 2002). Sometimes lost natural habitats are mimicked by urban areas, such as rocky habitats (Lundholm and Marlin 2006). These circumstances provide an opportunity for restoring or optimizing particular structural or functional components of the urban forest. All in all, if ecological integrity is seen in isolation either from a structural or functional perspective, then it is misunderstood. Biodiversity must be seen in conjunction with nativeness, as shall be discussed below.

Native species

Many studies demonstrate that urban forests have a significant or almost-dominant non-native-tree species composition, in Europe (Dunn and Henegham 2011), North America (Clemants and Moore 2003), and other places (e.g. China; Jim and Liu 2001). However, defining what is native is difficult. Because of the long history of urbanization in Europe, it is important to distinguish between old and naturalized (a.k.a. archaeophytes) and recent non-native (a.k.a. neophytes) arrivals in order to understand that species of various degree of nativeness contribute differently to the species diversity of cities (Cilliers and Siebert 2011). In North America's short history of urbanization, and in North American forestry, the term has come to mean species present before European colonization (Schwartz 1997). Colonization meant that non-native species of trees were planted in urban settings mostly because of hardiness and cultural preferences before ecological considerations were established (Werner and Zahner 2010).

It has been suggested that native species contribute to the integrity (Noss 1990) and stability (Mosquin 2000) of an ecosystem. Natives make the best use of resources available, control invasive species, make associations with wildlife, and keep the gene pool regulated (McKinney 2002). Some of these issues are explored in Table 2 with some examples from North America. Several points are clear: 1. Natives' use of resources varies depending on whether an area has a limiting resource and whether non-native species are effectively selected; 2. In landscapes that cannot support trees naturally, even native species need artificial care; 3. Unlike some native species (Gilbert 1989), many non-natives do well in cities because they are chosen to respond positively to anthropogenic stress and the reality of urbanization; 4. Depending on the species, connections to wildlife can sometimes be replaced by non-natives; and 5. Climate change challenges the persistence of some native species.

A focus on the technical implications of the arguments above may imply that the outcry for native planting is not grounded in urban forest reality (e.g. Schwab 2009). In turn, this may support a status quo in ecologically-poor considerations for tree species selection in the urban forest (Ware 1994). This idea reduces ecological considerations of nativeness to a technical problem. The functional and structural considerations for planting native species are not necessarily mutually exclusive. For example, a constructive notion of native species can be accommodating of climate change if the boundary at which nativeness is defined is stretched to a wider natural ecosystem (Ordonez et al. 2010). Moreover, native planting is

Table 2 Ecological functions of some native species in North America

Function	Native Species	Non-Native Species	Example
Water use	Natives use less water in water-restricted areas. Water-restricted areas cannot support even native trees and care is needed.	Some exotics need artificial irrigation, unless carefully selected.	(McCarthy and Pataki 2010; City of Calgary 2007)
Response to environmental conditions	E.g. Sugar maple (*Acer saccharum*). Does badly in some North American cities. Sensitive to air pollution levels. Needs more care. Thrives in natural areas.	E.g. Norway maple (*Acer platanoides*). Thrives in urban areas with less care. Colonizes unmanaged lands.	(Guntenspergen and Levenson 1997)
Contribution to natural processes	Natives contribute to more natural processes, i.e. nutrient cycling	Non-natives can optimize some natural processes, i.e. nutrient cycling	(Kendle and Rose 2000; Lovett and Mitchell 2004)
Resistance to diseases/pests	E.g. American elm (*Ulmus americana*). Threatened by Dutch elm disease in urban areas.	E.g. European linden (*Tilia europaea*). Thrives unthreatened in urban areas.	(Karnosky 2009; Turner et al. 2005)
Connections to wildlife	Natives provide particular connections to particular species, some specialists, some generalists.	Some exotics provide food and shelter as well as natives.	(Kendle and Rose 2000; Mörtberg 2001)
Response to climate change	Some natives may not survive temperature and weather changes.	Most non-native species are more flexible and may survive temperature and weather changes	(Yang 2009)

based both on a precautionary approach, which recognizes what we do not yet know about particular species and ecosystems (e.g. in terms of genetics), and on conservation values (Stewart et al. 2009). Over all, native species is a fundamental idea that contributes to the notion of ecological integrity, but it cannot be supported on functional, and thus technical, grounds alone.

Stressors

The less stressed an ecosystem is, the healthier and more biodiverse it is (Westra 2008). The urban forest is subject to a number of natural and, mainly, anthropogenic stressors that reduce the lifespan of many trees (Nowak et al. 2004). These may include unnatural hydrological cycling (Quigley 2004), low quality of soil (Zhu and Carreiro 2004), and direct disturbances (Florgård 2000), among many others (for a review, see Sieghardt et al. 2005). While anthropogenic stressors contribute to the lack of ecological integrity in an ecosystem (Freedman et al. 1995), some of the most devastating cases of urban forest loss in North America and in naturalized areas have been caused by weather (e.g. Halifax, Burley et al. 2008; and Vancouver, Lawson 2010). Moreover, other environmental conditions of urban areas, such as urban heat islands, may affect trees positively or negatively, whether native or non-native (Roetzer et al. 2000). In general, the environmental conditions of urban areas can be seen negatively as stress factors or positively as opportunities to understand the particularities of the urban ecosystems in general (Botkin and Beveridge 1997), and the urban forest in particular. It could be said that an urban environment with no stress is not an urban environment at all, but an urban environment that is too highly stressed makes it impossible for even the smallest shred of nature to survive. Arguing for techno-ecological standards based on the notion that anthropogenic stressors are always a given condition certainly does not respond to a holistic perspective of ecological integrity of the urban forest, one that requires many natural functions and structures to be preserved. Over all, stressors are manageable urban conditions that can be adapted to the decisions taken to maintain these desired features of the urban forest.

Resilience

An ecosystem retains its integrity when it is resilient, that is, when it can adjust to alterations of its patterns and processes and achieve stability within natural stochastic or anthropogenic changes (Holling 1973). An ecosystem's resilience must apply at all temporal and spatial levels, from the species level to the landscape level, and from the short term to the long term (Peterson et al. 1998). Resilience is heavily dependent on the functional and structural elements through which it is measured, such as health, biodiversity and nativeness, already discussed. Resilience is also dependent on the variety and complexity of stressors, such as the built infrastructure. Resilience of an urban forest patch to a hurricane can increase or decrease by direct threat or protection of buildings. This is, however, ecologically undesirable. If the urban forest relies on a definition of natural elements, then resilience should not be engineered through unnatural elements (Holling 1996).

A particular feature of resilience is habitat connectivity, which enhances the natural character of the urban forest and allows many ecological functions to take place (Alberti and Marzluff 2004). Nonetheless, enhancing connectivity may also mean amplifying some stressors. This is the case of non-native species domination of seed banks and diseases and pests. These two cases are of course dependent on both the species composition of the urban forest and other environmental conditions: wind, climate, humidity, frost events, and others.

While connectivity by itself gives no indication on how to achieve resilience if little is done about stressors, it is an important concept related to naturalness, which is crucial to the notion of ecological integrity.

Self-maintenance

Self-maintenance relates to the natural qualities of an ecosystem to evolve, change and self-regulate, and it is a crucial component of its integrity (Crabbé and Manno 2008). Self-maintenance is dependent on many ecological functions, and in that regard, it is inherently tied with ecosystem health, as much as with other components of integrity, such as stressors. Theoretically, and if given enough time, a stress-free urban forest has the capacity to undergo succession on its own and self-regulate and direct actions may not be necessary to achieve integrity. However, the idea of self-maintenance has not taken hold as a concept in urban forest management. For example, few trees in the urban core, except in backyard fenceline situations, come about without being planted. Threats such as invasive herbaceous species (Bornkamm 2007), or even socio-political issues, such as change in ownership or management regime (Hope et al. 2006), hinder the self-maintenance of the urban forest when defined against a natural standard. Ultimately, any decision for the sake of self-maintenance would in itself reflect a human-steered influence in the urban forest, as the biggest factor of change in the urban forest is short-term human decisions (Nowak 1993). However, as we have seen above, ecologically sound decision-making involves the maintenance of a certain degree of natural processes or structures that, in isolation, could be seen as self-regulating. Leaving parts of the urban forest without human intervention is a legitimate kind of management, because it is a conscious decision to act according to specific management goals, in this case, ecological integrity of the urban forest.

Framing urban forest ecological integrity

Two camps of interpretation

The discussion above shows how urban-forest ecological integrity is understood today. Two camps of interpretation are revealed. On the one hand, there is an understanding of ecological integrity as solely dependent of ecological functions. Urban forest health, for instance, is seen as the maintenance of ecological functions that influence environmental conditions and benefit people. This view has justified the artificialization of many natural functions by relying on technological and unnatural fixes, such as planting non-native species, structural soils, high-elevation tree beds, and artificial fertilization, among others. The betterment of the environmental conditions considered under this view certainly affect ecological processes, but this narrows the notion of integrity to a desired set of functions. Other components of ecological integrity such as biodiversity and resilience are adapted to fit this interpretation. For instance, biodiversity and resilience are translated into diversity standards that ensure the survival of most of the canopy cover against an outbreak of insects or disease. Integrity concepts that mostly reflect ecological structures, such as native species or wildlife associations, have not been embraced under this view. Moreover, this interpretation also narrows the scope of functional integrity to that of individual trees. Indicators such as canopy cover and individual tree health are fitted to this view. In general, this view reflects a utilitarian, anthropogenic or assigned-value viewpoint.

On the other hand, there is a deeper ecological view that supports the maintenance of ecological functions and structures at natural levels. Here, ecosystem health, biodiversity, native species, stressors, resilience and self-maintenance are managed according to the natural standards of a hinterland forest before urbanization. This camp prioritizes structural components, such as native species, to influence a different set of functional components, such as seed dispersal and support of wildlife. Measures of integrity for this camp are characterized by native species content, diversity of trees, habitats and genes, and a reliance on natural environmental quality based on hinterland forest baselines. One of the operational components of this view is to increase the number of naturalized urban parks.

Framing urban-forest ecological integrity

Different definitions of an ecosystem could elicit different discourses in ecological integrity discussions (Manuel-Navarrete et al. 2004). This is certainly the case for the urban forest. As the urban forest has been mostly defined as just the trees, the conceptualization of integrity as exposed by the first camp of interpretation is a logical outcome. If the urban forest is defined as a tree-dominated ecosystem with all its biotic and environmental associations, then the naturally-based interpretation of integrity exposed above is most fitting. This latter definition is ecologically useful as it strives for the maintenance of native species, natural diversity, the broadening and increased connectivity of tree stands and patches, reducing anthropogenic stress, and other elements and management opportunities discussed above. This notion ultimately responds to the importance we give to special connections in nature (Maurer et al. 2000) as defined by our understanding of what we consider good in nature (Sagoff 1992), that is, to the intrinsic value of nature (Ghilarov 2000).

A deeper perspective on how to frame our understanding of urban forest ecological integrity is revealed by a discussion of values. First, it is clear that the urban environment is interpreted as an ecosystem in different ways, thus triggering a different ecological understanding. A particular framing of the urban ecosystem may fit one or several interpretations of what an ecological concept means (Roberts et al. 2009). For the purpose of this discussion, we find that in order to integrate broader and deeper interpretations of ecological concepts, the most useful definition of the urban forest ecosystem lies in the human-nature landscape. The ecology of the urban forest then echoes the new paradigm of the so-called socio-ecological model. Many see the urban ecosystem, of which the urban forest is a part, as one such model (Pickett et al. 2008; Pickett et al. 2001; Zipperer 2011). Critics of this view adduce that cities can never be seen as ecological systems, as ecological values always conflict with sociocultural ones (K'Akumu 2007). This criticism is useful as it overcomes the reliance on anthropogenic values that characterizes the first camp of interpretation of ecological integrity exposed here. However, socio-ecological models are at a higher level of abstraction, where values are crucial to understanding them, and in so saying, where value integration rather than trade-off is the goal (Moffatt and Kohler 2008).

The urban forest can also be understood and managed under a socio-ecological model. Ecological functions and structures in the urban forest encompass both natural and artificial processes that operate differently than those of hinterland forests. This difference is due to a complex ecological dynamic that couples natural development processes with human processes, both of which operate at a variety of rates and affect one another in a variety of ways. The restoration of many desired ecological functions and structures of an urban forest will depend on the pursuit of this comprehensive notion of urban forest management and, in general, on the values we set out to manage. A values perspective is most fitting to understand ecological integrity, with the complex array of functions and structures that in entails, where anthropocentric value viewpoints intertwine with intrinsic values regarding the preservation of natural sustainable systems. Such a perspective requires that both the broader ecological landscape and the cultural aspects of the urban ecosystem be integrated. Under this light, using ecological integrity as a principle in urban forest management does not mean advocating for either camp of interpretation extracted here, but finding a discursive convergence point that argues for the management of comprehensive value sets. This is particularly relevant if stressors, native species, naturalness and wildlife connections are to be managed in parallel to the functional and environmental concerns that have hitherto characterized urban forest management.

Finally, ecological integrity should function as much as a principle as a perspective in sustainable urban forest management. Establishing a fixed model of integrity for the whole urban forest denies its variability of scale that defines its structural diversity. Common objectives, indicators and targets of health, stressors, nativeness and naturalness, and wildlife connections are impossible to achieve at all scales because the urban forest is ecologically specific at different scales. An urban forest with integrity on a street landscape is different than that of a naturalized park. However, this is not to say that the concept of integrity as a tool of management is useless. Rather, differentiated targets can be designed around a common goal of integrity and applied in a continuum of management regimes, from the trees in the urban core to a naturalized park. This should be the ultimate practical use of ecological integrity when used as a management directive.

Conclusion

Urban forest management plans across North America have started to guide the management of urban forests according to the notion of ecological integrity (Ordonez and Duinker 2012). We have discussed the concepts associated with this tool of management and revealed the complexity of understanding it for urban forest ecosystems under the lens of ecosystem values. Only a comprehensive array of concepts spanning all functional and structural components of an urban forest's ecological integrity may serve an ecologically sound management of the urban forest. However, today urban forest management leaves much to be desired in this regard. Canopy cover, for example, is the most-used indicator of how well the urban forest is doing. This certainly does not reflect our full understanding of what ecological integrity means for the urban forest and does not include some of its most important criteria, such as ecosystem functionality at the forest-patch level, diversity of species, habitats and genes, wildlife associations, native species content, and reduction of stress. Using this conceptualization of ecological integrity would allow for multi-level, multi-spatial, long-term and, overall, ecologically-sound urban forest management in the future.

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