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# Managing Cities as Urban Ecosystems: Fundamentals and a Framework for Los Angeles, California

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# Managing Cities as Urban Ecosystems: Fundamentals and a Framework for Los Angeles, California

Ecosystem-based frameworks offer a robust platform for managing complex ecological challenges associated with land management. Actionable frameworks for urban ecosystems are just emerging, and the purpose of this essay is to support advancing application in city management contexts. Comprehensive urban ecosystem frameworks have the potential to synergize interrelated, yet often siloed, urban environmental management themes including urban biodiversity and natural features, pollution management, ecosystem services enhancement, and natural hazards; particularly as urban sustainability, resiliency, and infrastructure initiatives increasingly reshape cities and elevate consideration of these topics. This essay begins with a review of fundamentals of urban ecosystems across multiple relevant disciplines leading to a proposed framework for comprehensive urban ecosystem management. It concludes with an application of the framework to create urban ecosystem typologies, a foundational tool in ecosystem management, within the context of Los Angeles, CA, USA. The conceptual framework may be adapted for other cities, particularly those with similar ecologies such as Mediterranean cities.

## **Keywords**

urban ecosystem, urban ecology, landscape ecology, ecosystem services, ecosystem health, ecosystem typologies, ecosystem mapping, landscape ecosystem method, urban planning, environmental planning, ecological planning, green infrastructure, resiliency, sustainability

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## INTRODUCTION

Sustainability efforts in cities worldwide are expanding to include more careful consideration of urban ecosystems. Local ecosystems provide a variety of benefits to cities and nature, such as supporting biodiversity and ecosystem services. They also play a central role in shaping impacts associated with cities, such as pollution and natural hazards. Importantly, many emerging hazards of climate change, from sea level rise to extreme heat events, result from impacts to local ecosystems. Realigning urban infrastructure to provide greater ecosystem services and accommodate climate change impacts is increasingly central to resiliency and infrastructure strategies. Ecosystem management techniques, principles, and frameworks, traditionally applied in more natural settings, offer cities new directions and opportunities to manage these emerging opportunities and challenges. I use the term, “management” of cities, to refer to activities associated with planning, design, architecture, engineering, operations, maintenance, and use of landscapes, built areas, and infrastructure.

Urban ecosystems can be thought of as dynamic combinations of natural, constructed, and social features associated with an urban area. They have been framed as “ecology *in* the city”, a phrase used to describe early scholarly work on the topic that focused on natural areas, biota, and natural ecosystems within urban areas. More recently, urban ecosystems have been framed as “ecology *of* the city”, which views entire urban areas as ecosystems, including built features and socio-economic systems (Pickett et al. 1997, 2001). “Ecology *for* the City” is a recent concept that emphasizes how the interaction of science and actions by decision makers are a main driver shaping urban ecosystems. Essentially, of how place-based science is shaping urban ecosystems at an accelerating rate due to the expansion of urban sustainability and resiliency initiatives and applied research (Childers et al. 2015). Such strong human dimensions are a defining feature of urban ecosystems and are integral to creating effective management frameworks. Like all ecosystems, urban ecosystems can also be thought of as spatial units, interconnected and organized within a nested hierarchy of spatial scales. At each scale, urban ecosystems may be classified and partitioned by different combinations of social and environmental processes and features. As has been done in more natural areas, these classified combinations (i.e., ecosystem types) may become useful tools in urban ecosystem management (Barnes et al. 1982; Grove et al. 2015; McPhearson et al. 2016; Pickett et al. 1997, 2001; Wu 2014).

In this essay, I present a framework for managing cities as urban ecosystems. The framework emphasizes the interactions between cities and their local physical environment (i.e., proximal ecosystems). Examples of such interactions include management of stormwater affecting local hydrology, or urban forests affecting a city’s urban heat island and biodiversity. The city’s broader ecosystem context, and interactions with less-proximal ecosystem processes are also important and widely addressed through urban sustainability frameworks such as management of city greenhouse gas emissions or imported water impacts on remote watersheds. This urban ecosystem framework generally addresses these broader aspects insofar as they relate to management of local urban landscapes, biota, and natural features such as landscape carbon storage or local hydrology implications of imported water. The framework exploration aims to expand upon and reframe earlier scholarly work on urban ecosystems by Pickett et al. (2001) and others by revisiting foundational science related to the topic, incorporating recent theoretical and applied research advances, and considering current trends in city sustainability and climate

change resiliency management. I present an example application of the framework that includes creation of conceptual urban ecosystem typologies for Los Angeles (L.A.), with the aim of inspiring new insight on the value of the ecosystem concept for urban areas and to advance ongoing management activities in L.A. and other cities.

## FUNDAMENTALS OF URBAN ECOSYSTEMS

The concept of urban ecosystems is addressed across many fields of science including landscape ecology, ecosystem services science, ecosystem health, conservation biology, environmental science. It is also increasingly being addressed in sustainability science, architecture, engineering, urban design, and urban planning. Scholars within these fields tend to address the topic from defined realms of supporting science and have developed distinct perspectives; but have evolved considerable conceptual overlap (Grove et al. 2015; McPhearson et al. 2016; Pickett et al. 2001; Wu 2014). A review of these fundamental perspectives and concepts can help identify key contributions from each field, leading toward a more complete understanding of urban ecosystems and their management. These fundamentals also provide the basis for creating a strong set of definitions related to urban ecosystem management, an important step often lacking in many literature examples related to the topic (Haase et al. 2014).

### Defining Urban Ecosystems

Definitions of the term “ecosystem” vary substantially, and vagueness or lack of definition is common throughout scholarly literature that utilizes the term. Understanding among the non-scientific and professional community also varies; a prevailing perception of the term in Los Angeles, for example, tends to be analogous to “habitat” or “natural areas”. The concept of “urban” ecosystems only adds to the confusion. Some definitions of “ecosystem” and “urban ecosystem” are provided in Table 1, along with key related definitions discussed in the following sections of this essay.

Table 1: Definitions relevant to the concept of urban ecosystems

| <b>Ecosystem</b>   |   |
|--|---|
| <i>“the whole system (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment...”</i> ; <i>“...the basic units of nature on the face of the earth”</i> ; to <i>“overlap, interlock and interact with one another”</i> and to <i>“show organization”</i>   | Arthur Tansley (1935)                     |
| <i>“dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit”</i>   | Convention on Biological Diversity (1992) |
| <i>“Ecology is, or should be, the study of ecological systems that are home to organisms at the surface of the earth. From this larger-than-life perspective, ecology’s concerns are with volumes of earth-space, each consisting of an atmospheric layer lying on an earth/water layer with organisms sandwiched at the solar-energized interfaces. These three-dimensional air/organisms/earth systems are real ecosystems – the true subjects of ecology,”</i> <i>“...we conceive the Ecosphere and its landscapes as ecosystems, large and small, nested within one another in a hierarchy of spatial sizes”</i> | Barnes et al. (1998)                      |

Table 1, continued

|  |  |
|--|--|
| <i>“All ecosystems are affected by the same broad suite of state factors: 1) prevailing climate, 2) the substrate, 3) the resident organisms and their residual effects, 4) relief, including elevation, slope, and aspect, and 5) the time over which the first four factors have been acting...”; and, “...in urban ecosystems, organisms must include humans and their social and economic manifestations...as well as native and introduced [biota]”</i> | Pickett et al. (2011),<br>Chapin et al. (2002) in<br>Pickett et al. (2011) |
| <i>Defining novel ecosystems: “have species compositions and relative abundances that have not occurred previously within a given biome. The key characteristics are (1) novelty: new species combinations, with the potential for changes in ecosystem functioning; and (2) human agency: ecosystems that are the result of deliberate or inadvertent human action, but do not depend on continued human intervention for their maintenance.”</i>           | Hobbs et al. (2006)  |
| <b>Urban Ecosystem</b>   |  |
| <i>“Urban ecosystems are those in which people live at high densities, and where built structures and infrastructure cover much of the land surface.”</i>  | Pickett et al. (2001)  |
| <b>Urban Ecology</b>   |  |
| <i>“a sub-discipline of ecology concerned with the distribution and abundance of plants and animals in towns and cities”</i>   | Rebele (1994)  |
| <i>“the study of spatiotemporal patterns, environmental impacts, and sustainability of urbanization with emphasis on biodiversity, ecosystem processes, and ecosystem services.”</i>   | Wu (2014)  |
| <i>“the scientific study of the processes determining the abundance and distribution of organisms, of the interactions between organisms, of the interactions between organisms and the environment, and the flows of energy and materials through ecosystems...within urban systems”</i>  | Gaston (2010)  |
| <i>“urban ecology integrates both basic and applied, natural and social science research to explore and elucidate the multiple dimensions of urban ecosystems”</i>   | McDonnell (2011)   |
| <i>Describing a common perception from an urban planning perspective: “urban ecology has focused on designing the environmental amenities of cities for people, and on reducing environmental impacts of urban regions”</i>  | Pickett et al. (2011)  |
| <b>Ecosystem Integrity</b>   |  |
| <i>“the ability of an ecosystem to maintain its organization in the face of changing environmental conditions”</i>   | Adapted from Kay (1991)  |
| <i>“the capacity of ecosystems to self-organize based on their structures and processes”</i>   | Burkhard et al (2012),<br>Muller 2005)                                     |
| <b>Ecosystem Health</b>  |  |
| <i>“ecosystem health as the absence of disease, and disease here was defined as the failure of the ecosystem to function within acceptable limits, thereby leading to an inadequate homeostatic repair mechanism.”</i>   | Schaeffer et al. (1988) in<br>Lu et al. (2015)                             |
| <i>“a healthy ecosystem is defined as being stable and sustainable; maintaining its organization and autonomy over time and is resilience to stress.”</i>  | Costanza (1992)  |

Table 1, continued

|  |   |
|--|---|
| <i>“a desired endpoint of environmental management, but it requires adaptive, ongoing definition and assessment.” And “a comprehensive, multiscale, dynamic, hierarchical measure of system resilience, organization, and vigor”... “a healthy and sustainable system in this context is one that attains its full expected life span”</i>   | Costanza and Magneau (1999)   |
| <b>Urban Ecosystem Health</b>  |   |
| <i>“a healthy ecosystem is a social-ecological unit that is stable and sustainable, maintaining its characteristic composition, organization, and function over time while remaining economically viable and sustaining human communities.”</i>  | Muñoz-Erickson, Aguilar-González, and Sisk (2007)                                 |
| <i>“...designing healthy ecosystems, which may be novel assemblages of species that perform desired functions and produce a range of valuable ecosystem services.” And “design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both.”</i>   | Costanza (2012) regarding application in Ecological Engineering                   |
| <i>“Urban ecosystem health integrates ecological, economic, social and human health factors, and including not only the health and integrity of the natural and built environment, but also health of urban residents and whole society.”</i>  | Su et al. (2013)  |
| <b>Urban Ecosystem Services</b>  |   |
| <i>In McPhearson et al. 2016: “the benefits urban residents derive from local and regional ecosystem functions,” that, “are co-produced by people and ecosystems.”</i>   | Andersson et al. (2015a); Larondelle et al. (2014), Gomez-Baggethun et al. (2013) |
| <b>Landscape Ecology</b>   |   |
| <i>defining landscape: “areas that are spatially heterogeneous in at least one factor of interest”, and “may occur across gradients which ecosystems do not necessarily repeat or occur.”</i>  | Turner, Gardner and O’Neil (2001)   |
| <i>in Opdam et al. (2013): a highly interdisciplinary and transdisciplinary science of environmental heterogeneity “that aims to understand and improve the relationship between spatial pattern and ecological processes on a range of scales with the goal of achieving landscape sustainability”</i>  | Wu (2013) in Opdam et al. (2013)  |
| <i>in Valles-Planells, Galiana &amp; Van Eetvelde (2014): “Landscape...is a holistic, spatial, and mental dynamic entity, which is the result of people place interactions.” And, “Its dual dimension, material and immaterial, implies that landscape is not just a geographical entity composed of abiotic, biotic, and human-made elements, but is also our perceived environment.”</i> | European Landscape Convention (Council of Europe 2000)                            |

Definitions of “ecosystem” range from biocentric, with the CBD definition implying that biotic communities (assumed to be mean “native” communities) are the defining feature of an ecosystem; to more expansive definitions, with Tansley (1935) presenting the original concept of wholistic, interconnected biotic and abiotic systems. Such wholistic definitions are more relevant to comprehensive urban ecosystem management since the topic must address a broad range of topics; some of which emphasize biota like urban biodiversity, while others, such as flood hazards, are more strongly influenced by abiotic properties like infrastructure form, physiography, and climate.

A useful definition for the urban environment must also accommodate human dominated landscapes and built features. Hobbs et al. (2006) description of novel ecosystems is suitable to address the unique biotic aspects of urban ecosystems that are heavily influenced by human processes, but are not completely dependent on them. Pickett and Grove (2009), argue that Tansley's "concept can be clarified for urban use by including a social complex and a built complex to ensure that human social institutions and actions, and the structures and infrastructure they build are explicitly included in the ecosystem concept." Combining "built" and "social" concepts with Barnes et al.'s (1998) concept of ecosystems as interconnected three-dimensional units combining "air", "earth", and "organism" properties is useful in that it allows for relatively simple characterization and mapping of urban ecosystem "types" in a hierarchy of spatial scales. As has been demonstrated over decades in natural lands management, successful definition of the ecosystem concept for urban areas may also provide an effective basis for managing cities as ecosystems.

Many foundational papers relevant to urban ecosystem management limit their use of the term "ecosystem", and more frequently refer to "urban ecology". Urban ecology studies tend to focus on specific urban ecosystem functions or features, often without explicitly addressing the broader concept of ecosystems. Proposed by Ernest Haeckel in 1866 from the Greek oikos, meaning home place, the term ecology means "knowledge of home" or "home wisdom" (Rowe 1989). Like "ecosystem", some definitions of "urban ecology" also include a biological emphasis, while Wu (2014) and others present more encompassing definitions that align well with comprehensive ecosystem management concepts. It is important to note the common perception of urban ecology from an urban planning perspective provided by Pickett et al. (2011). They suggest that a majority of professional work related to urban ecology is performed by urban and environmental planners, designers, and engineers in the context of pollution management, environmental hazards, species protection, and creation of landscape amenities. These more traditional topics are often highly institutionalized in city management and governance structures. While current scientific efforts in urban ecology tend to favor emerging topics like urban ecosystem services, green infrastructure, or urban biodiversity; comprehensive urban ecosystem management frameworks should also seek to integrate these long-established and well-funded management institutions.

### **Urban Ecosystem Health**

The term "ecosystem health" has been used to describe the relative state of an ecosystem. Effective management of ecosystems often relies on determining a desired ecosystem state and setting associated targets and plans for management. Indicators and measurement systems are an essential tool for ensuring management targets are reached, and the term "health" has been useful in defining such systems in a variety of environmental management contexts. Examples include United States Forest Service's Forest Health Management programs and the United Nation's use of "ecosystem health" in their ecosystem management agenda (Lu et al. 2015, UN General Assembly, 1992). Watershed "health" is also widely applied concept in urban Los Angeles.

Importantly, in the context of Los Angeles, the term "ecosystem health" is also being used in a high-profile initiative called the UCLA Los Angeles County Sustainability Grand Challenge (UCLA 2016). This effort aims to leverage the research capacity of UCLA to achieve 100% local energy and water supply, and enhanced ecosystem health, in the County by 2050.

The term “ecosystem health” was viewed as easy to grasp across a broad scientific, decision maker, and layperson target audience of the project, and was chosen over related terms like ecosystem services or ecosystem integrity<sup>1</sup>.

More broadly, the term ecosystem health has been used in urban and rural contexts in two ways: 1) as a metaphor to communicate the condition of an ecosystem; and, 2) as an operational concept to define indices for measuring ecosystem condition and outcomes of management decisions (Sutter 1993, Munoz-Erickson, Aguilar-Gonzalez & Sisk 2007). Early literature on the topic emphasizes quantification and modeling of ecosystem properties relating to structure (organization), function (vigor), and resilience to stress over time in natural lands contexts (Costanza and Magneau 1999). More recently, Munoz-Erickson, Aguilar-Gonzalez & Sisk (2007) describe ecosystem health as a preferred state of ecosystems that are economically viable and sustain human communities. They emphasize the importance of decision makers in shaping ecosystem health, and that inherent value judgements and public involvement are necessary in developing management strategies or health objectives. Based on this perspective, healthy ecosystems can be in essentially any form, engineered or natural, if they provide an acceptable level of perceived ecosystem services benefits (Lu et al. 2015). Costanza (2012) directly describes engineered novel ecosystems and landscapes in an urban context as capable of being “healthy”. Clearly, the concept has evolved to reflect an expanded view of ecosystems that incorporate urban contexts and built and social structures. However, while conceptual approaches for comprehensive urban ecosystem health applications exist, see Lu et al. (2015), there are few, if any, city-scale examples that have been applied in management. Therefore, while “ecosystem health” is an appropriate metaphor and umbrella term for urban ecosystem management indicators or objectives, effective operational constructs have yet to be developed.

## Urban Ecosystem Services

Ecosystem services are the benefits people obtain from ecosystems (MEA 2003). They are typically classified into four categories as: 1) *provisioning services*: the outputs that people use from ecosystems such as timber or water; 2) *regulating services*: ecological functions such as maintaining air and soil quality; 3) *supporting services* the such as biodiversity or landforms that maintain underlying ecosystem functions; and 4) *cultural services* such as mental health benefits, recreation, or educational opportunities. Services are typically measured in terms of social, economic or ecological valuations, and several ecosystem services classifications systems have been developed and applied including: comprehensive frameworks (e.g., Haines-Young and Potschin 2010; Teeb 2011), tailored classifications in applied research projects (e.g., McPhearson, Kremer, and Hamstead 2013, Plan NYC 2011), as well as many emerging professional applications in city management projects (e.g., NYC 2016, SFPUC 2013, Los Angeles pLAn 2017).

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<sup>1</sup> Ecosystem integrity is another concept relevant to ecosystem management, but its applications tend to emphasize natural areas. Further exploration of the utility of the concept to address comprehensive urban ecosystems, potentially as a measure of the “naturalness” or “intactness” of remnant natural ecosystem properties across cities, may be beneficial.



Urban ecosystem services research is strongly influenced by traditional environmental sciences and ecosystem services applications in rural areas. Research emphasizes the ecosystem functions and processes that either: produce urban ecosystem services (i.e., ecosystem services supply) such as carbon storage, urban heat island mitigation, or water quality improvement; or result in benefits (i.e., ecosystem services demand) such as reduced energy use or improved public health. Many recent studies have pointed to the increasing role of urban ecosystem services in ensuring resilient, livable, and sustainable cities, particularly related to climate change adaptation (Elmqvist et al. 2015, McPhearson et al. 2015). However, integration of ecosystem services into urban planning, design, engineering, and governance has been slow and there are still few examples of applied research (de Groot et al. 2010; Haase et al. 2014; McPhearson et al. 2016). To improve integration, the field better must engage other disciplines associated with urban management; particularly social science, urban planning, design, and engineering professionals who shape land use, infrastructure, and policy; and the values and perceptions of land owners who often manage the largest amount of area available for ecosystem services enhancement in cities. As Ahern, Cilliers, and Niemelä (2014) point out, “the challenge of providing ecosystem services for urban sustainability planning and design will rely on emerging urban planning and design theory and new knowledge in design and engineering. Transdisciplinary, implying co-production of knowledge by scientists, planning professionals and urban dwellers is a key to realize the potential of this planning approach.”

The relationship between urban ecosystems and urban ecosystem services is complex. Rapport, Costanza, and McMichael (1998) theorized that healthy ecosystems enhance provision of ecosystem services. Haase et al. (2014) refer to ecosystem functions (and degradation) as the basis for urban landscapes to build adaptive capacity and provide ecosystem services. In Table 1, the definition of urban ecosystem services provided in McPhearson et al. (2016) includes the idea that urban ecosystem services are “co-produced by people and ecosystems”. This implies that many, if not most, urban ecosystem services are generated by landscapes with embedded ecosystem functions either intentionally, or incidentally, shaped by people (Pincetl 2015). Therefore, the perceptions and values of the people that make management decisions are key features of urban ecosystems and services, along with the natural physical properties of the land. Many of these decisions derive from the desire for “cultural ecosystem services”, predominantly by creating landscapes with aesthetic or recreational value, or for compliance with local environmental regulations or building codes. The role of culture and perception in shaping urban ecosystems cannot be understated, and Andersson et al. (2015b) went so far as to argue that cultural ecosystem services are “the gateway for improving urban sustainability” (Bertram and Rehdanz 2015, Daniel et al. 2012).

Ecosystem services is an important concept for comprehensive urban ecosystem management, and can be a central theme for managing the benefits urban ecosystems provide to people. However, with its human-benefits and supply and demand focus, the ecosystem services concept alone is not well suited to fully address other aspects of comprehensive urban ecosystem management related to: 1) urban biodiversity and natural features when considering benefits to nature for nature’s sake; 2) environmental pollution impacts that cannot be fully managed with ecosystem services strategies alone; or 3) comprehensive management of ecological hazards such as wildfires, riparian and coastal flooding, landslides, or extreme heat events which often incorporate engineered “gray” infrastructure-based solutions and complex urban planning and risk management frameworks.

## **Landscape Ecology**

The field of Landscape Ecology has provided a broad contribution to urban ecosystem management with an emphasis on applied research and human dimensions. It is a highly interdisciplinary field focused on understanding social-ecological patterns and processes at multiple special scales, with strong connections to urban and landscape planning, policy, architecture and design, and conservation biology. The concept of landscape, and its relationship to ecosystems, is integral to the study of urban ecosystems, yet has not been widely integrated across other disciplines. Wu (2014) points out that, “[landscape ecologists], urban planners, and geographers often deal with the city as a landscape that has patches, corridors, and the matrix”...”but for most other ecologists, studying the city in a spatially explicit manner, or choosing the urban landscape, including the city and its surrounding areas as the study site, is relatively new (Foreman 1995, 2008a, 2008b).” Ahern (2013) argues that the field of landscape ecology “provides the concepts and tools to understand, model, and manage the frequency, magnitude, and extent of urban ecosystem dynamics” (Nassauer and Opdam 2008).

Historically, landscapes have been differentiated from ecosystems as being the result of the interaction between natural and human processes. However, more recently, many publications addressing urban ecology have absorbed the concept of landscape by defining human processes and perception (key determinants of urban landscape character) as a component of urban ecosystem processes, e.g., Pickett et al. (2011), Grove et al (2016), Munoz-Erickson, Aguilar-Gonzalez & Sisk (2007), Costanza (2012). Landscape ecologists will point out, however, that a wealth of landscape ecological science has addressed important gaps in other disciplines including human processes dimensions, and the role of landscape configuration and pattern in urban ecosystem function (Valles-Planells, Galiana & Van Eetvelde 2014, Termorshuizen & Opdam 2009). Recognizing landscape ecology as a distinct discipline for understanding urban ecosystems, particularly their patterns and what shapes them, is important for broader integration and application; especially since the field is so closely aligned with urban planning, design, and landscape architecture, all dominant fields in shaping urban environments (Valles-Planells, Galiana & Van Eetvelde 2014, Termorshuizen & Opdam 2009, Mucacchio 2009, Nassauer 2012, Wu 2014.) .

## **Sustainability and Resilience**

Many recent papers have pointed out that urban ecosystems are integral to urban sustainability and resilience (Musacchio 2009, Ahern 2013, Haase et al. 2014, Wu 2014, Colding, and Barthel 2015, Elmqvist et al. 2015, McPhearson et al. 2015). Examples of applied urban ecosystem management initiatives often occur under the umbrella of comprehensive sustainability or resiliency planning (e.g., GreenOLA 2008, Plan NYC 2011, Singapore Green Plan 2012, UCLA 2016, Los Angeles pLAN 2017). Like management of pollution and environmental hazards, sustainability has become institutionalized in many cities. Comprehensive sustainability efforts often include frameworks that integrate multiple disciplines of energy, transportation, water supply, stormwater, green building, waste management, urban ecosystem services, and biodiversity, etc. These higher-profile, and often more well-funded, project contexts may increase the likelihood of effective implementation of urban ecosystem management strategies

compared to “stand alone” efforts, which are often created by scholars or more ecologically-oriented non-governmental organizations. Fostering synergies and “win-win” solutions across multiple disciplines may also lead to more effective implementation.

Importantly, many effects of climate change, usually the drivers of urban resiliency projects, result in direct impacts to local ecosystems, providing an opportunity for applying urban ecosystems frameworks. Examples include changing precipitation and temperature patterns effecting vegetation and hydrology of stormwater management systems or watersheds; or extreme heat events increasing the demand for urban ecosystem services from urban forest canopies. Human behavior responses to changing climates also lead to urban ecosystem change. For example, widespread conversion of turf lawns to water efficient landscapes in Los Angeles may be altering the urban heat island, urban forest canopy, and dynamics of local waterways. Comprehensive urban ecosystem frameworks may be used to optimize these complex changes to urban ecosystems to improve a city’s “resilience” to impacts (ability to recover), “resistance” to impacts (ability to absorb shocks), or ability to “respond” to impacts (adapt to change) (Chapin, Matson, and Mooney 2002). Integration of “resiliency” concepts in city planning is just beginning, and the role of urban ecosystems in addressing the profound and long-term hazards of climate change are a key emerging direction.

## A FRAMEWORK FOR URBAN ECOSYSTEM MANAGEMENT

Drawing from the above disciplines and definitions, the following framework incorporates fundamental components of urban ecosystems into a comprehensive management framework (see Figure 1). The framework is organized around four central management themes: biodiversity & natural features, ecosystem services, ecological hazards, and pollution. Figure 2 presents some example management topics commonly addressed within each theme.

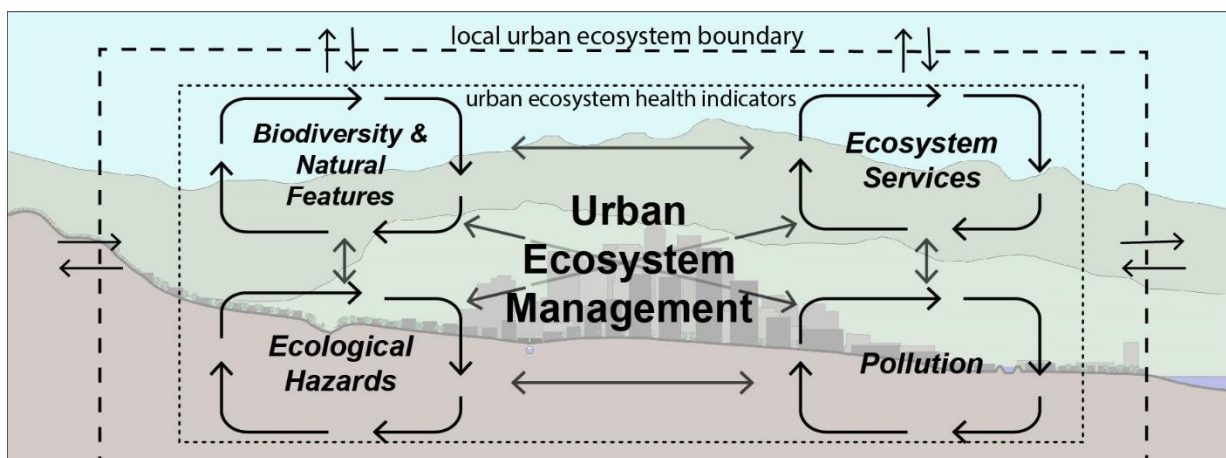


Figure 1: Proposed comprehensive urban ecosystem management framework

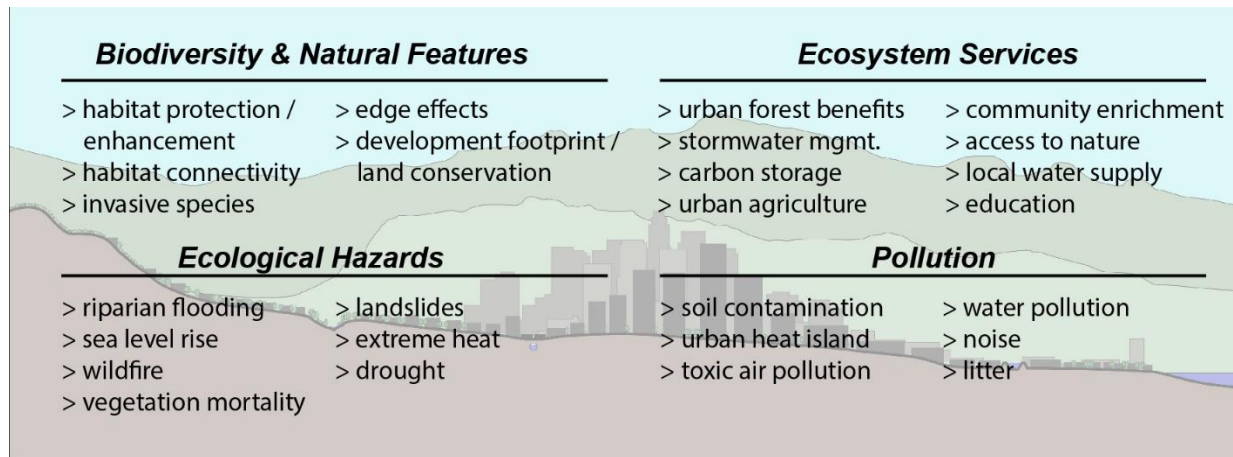


Figure 2: Management themes and example topics for Los Angeles

The management themes and example topics demonstrate a framework that addresses both benefits and impacts of the urban ecosystem to people and nature. The framework provides new opportunities for integration across the four categories including leveraging of interrelationships between themes for more effective management (e.g., urban ecosystem services to reduce urban pollution and protect from climate hazards, or biodiversity as an indicator of pollution levels). The state of the urban ecosystem, and the effectiveness of management, may be described by the term “urban ecosystem health”, denoted by the dotted box. The framework emphasizes a local urban ecosystem extent, denoted by the dashed box symbolizing local decision realm and physical ecosystem extent. Some management aspects of the local urban ecosystem may have local effects (e.g., urban heat island, UHI, effects on public health) and/or global effects (e.g., urban forest carbon sequestration, increased GHG emissions from UHI influencing climate change). The framework may be expanded to address broader ecological extents and interactions of the city ecosystem with the surrounding region or globally. I propose the following definitions related to management of urban ecosystems:

**Urban ecosystems:** Dynamic, three-dimensional combinations of natural, social, and built features, and their functions, associated with an urban area.

**Urban ecosystem functions:** The result of pattern, structure, and/or processes of urban ecosystems (i.e., ecosystem properties) over time. Functions occur throughout the urban area, but are often concentrated within urban landscapes that are influenced by associated built, socio-cultural, and natural contexts.

**Urban ecosystem services:** The human benefits resulting from urban ecosystem properties and associated functions.

**Urban ecosystem health:** A measure of the biodiversity, ecosystem services, pollution, and hazards associated with urban ecosystems in terms of benefits or impacts to people and nature.

**Urban ecosystem types:** Urban ecosystem units with relatively homogeneous combinations of ecosystem properties or functions, which may be classified, partitioned, and mapped in a nested hierarchy of special scales across an urban area.

An important implication of the framework is to support development of urban ecosystem maps and types as management tools. The concept of urban ecosystem types is described throughout the remaining sections of this essay. Urban ecosystem types include relatively homogeneous areas of analogous ecosystem properties or functions and can be used as a tool to facilitate application of management strategies. An example framework of urban ecosystem properties is presented in Figure 3, which may be used as a basis to classify urban ecosystem types. The properties framework builds upon the idea of ecosystems comprising a three-dimensional layered structure described by Barnes et al. (1998). It includes examples of prevailing ecosystem properties within each layer and is encompassed by social properties drivers.

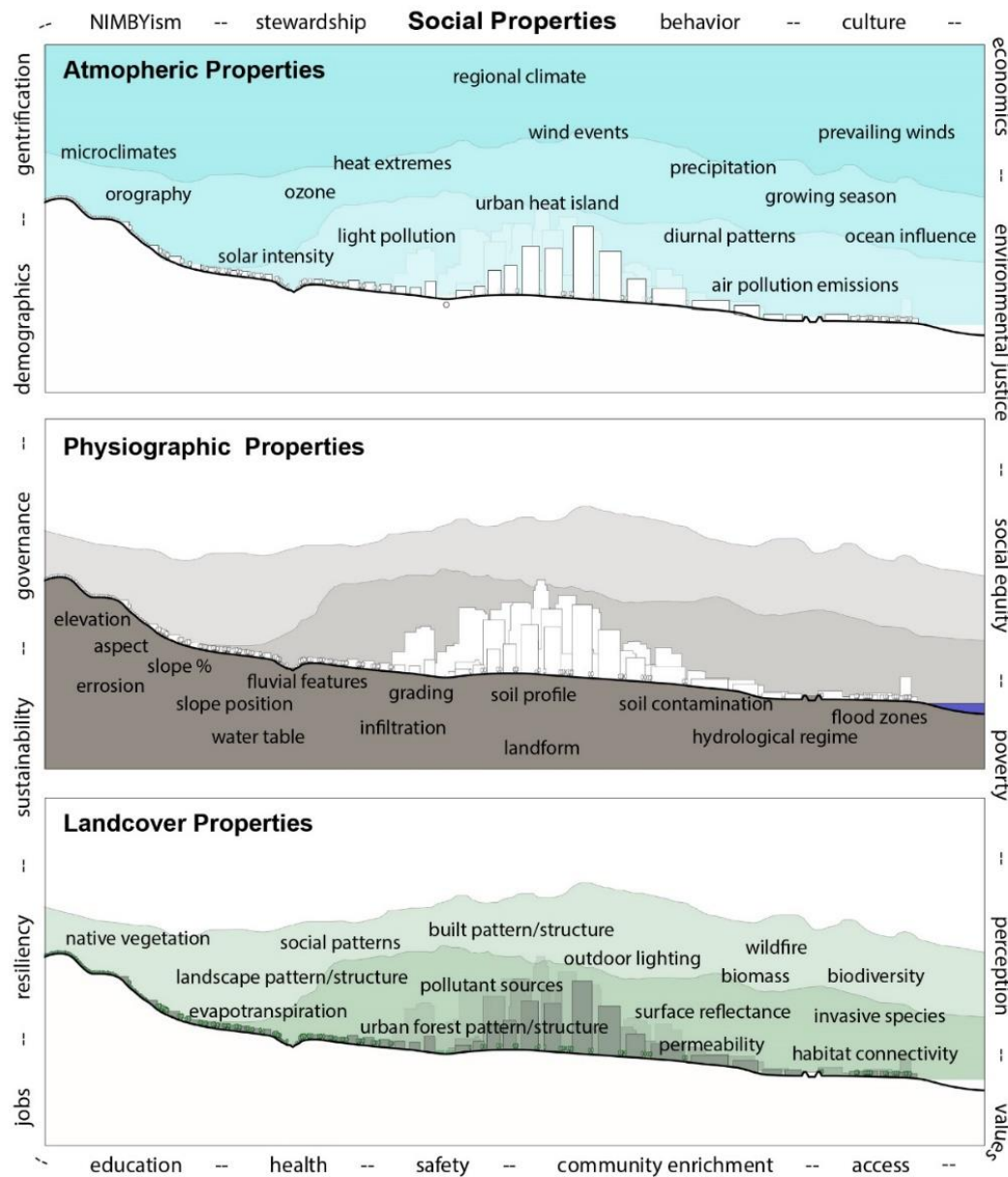


Figure 3: Example urban ecosystem structural layers and properties.

## **URBAN ECOSYSTEM TYPES: A FRAMEWORK APPLICATION TOOL**

Ecosystem typologies and associated maps have been used as a management tool in natural-resource based landscapes for almost half a century. When used effectively, these tools can become a key medium for managing comprehensive ecological performance (Margules and Pressey 2000, Kain et al. 2016, Kramer et al. 2016). In the final section of this essay I discuss conceptual urban ecosystem typologies for Los Angeles that may be used to provide integrated, place-based management of the framework's four management themes; and as a basis for understanding and organizing the city as a comprehensive ecosystem unit.

Like land use types —the central unit of urban planning practice— urban ecosystem types may effectively integrate complex spatial, structural, and functional information from multiple environmental disciplines into an effective tool that supports transfer and integration of ecological information across disciplines (Streenberg et al. 2015, Lehmann et al. 2014). In typical urban planning, design, and infrastructure projects, spatially explicit ecosystem-based information is often only partially available for project sites, and is often fragmented across wide ranging disciplines and datasets (e.g., biology, hydrology, geology, air quality, public health, urban design, etc.). Planners, designers, and other managers often analyze sites independently, and propose strategies based on this fragmented information, without the opportunity to integrate with broader, city-wide urban ecology contexts or coordinated strategies across multiple management sites. City-wide application of urban ecosystem typologies and maps may provide a “coordination and integration platform” to disseminate comprehensive information regarding site ecosystems and objectives, and to optimize benefits of broad-scale ecological opportunities, such as enhancing urban habitat connectivity, optimizing supply and demand of urban ecosystem services across cities or neighborhoods, and addressing broad-scale ecological hazards and pollution.

### **Creating Typologies**

A key first step in creating typologies is to perform an ecosystem characterization for the area of interest. Ecosystem types can be of any size, shape, or scale, and boundaries are usually drawn to answer a particular question (Pickett et al 2011, Tansley 1935). Therefore, characterization may involve assessment of ecosystem properties relevant to management objectives, which are then classified into relatively homogeneous management units (Streenberg et al. 2015). While there are few scientific precedents for such comprehensive classifications in cities, examples are common in natural resource management contexts. The “landscape ecosystem method”, employed by Barnes and others, includes well developed methods for characterizing natural ecosystems that have been applied extensively in forest and landscape management (Barnes et al. 1982, Barnes 1993, Lapin and Barnes 1995). This method is the basis for the U.S. Forest Service's ecological land classification system, which has been used to map ecosystems across the United States (Cleland et al. 1997). The system includes the ecological region surrounding Los Angeles and is an important starting point for this framework application (see Figure 5).

Determining the ecological properties to consider in a classification is often based on research or management priorities. Pickett et al. (2011) synthesized literature from over a decade to organize key ecosystem properties related to urban ecosystem services into the following categories:

- Urban heat island pattern
- Urban heat island effects
- Atmospheric accumulation
- Urban hydrology
- Urban stream syndrome
- Streams as bioreactors/transformers of nutrients
- Urban soil alterations
- Soil moisture
- Soil contamination
- Soil C and N dynamics
- Urban vegetation
- Urban vegetation heterogeneity
- Urban animals
- Trophic dynamics
- Urban footprint
- Pollution and nutrient dynamics
- Social ecology
- Social differentiation
- Invasive species and biogeochemistry

Pickett’s categories represent a blend of structure and pattern properties, such as urban heat island pattern or urban footprint, and functional properties such as Soil C and N dynamics or hydrology. Other ecosystem mapping processes rely on more basic structural properties of ecosystems, such the landscape ecosystem method, which partitions ecosystems based on combinations of atmospheric, physiographic, and biota properties including the following list and map example in Figure 4. These basic structural properties can be effective because they tend to be easier to map because they are visible; are fairly simple to measure using existing datasets; and/or because they can be used as indicators of more complex functional patterns and processes that are more difficult to measure directly (Nassauer 2012).

- Landform
- Aspect
- Slope %
- Slope position
- Elevation
- Soil parent material
- Soil profile classification
- Soil moisture
- Seasonal high/low temperature
- Seasonal precipitation
- Wind
- Solar energy profile
- Plant community structure type
- Plant species by structural layer
- Indicator flora/faunal spp.
- Disturbance profile (flood, fire, erosion, browse, etc.)

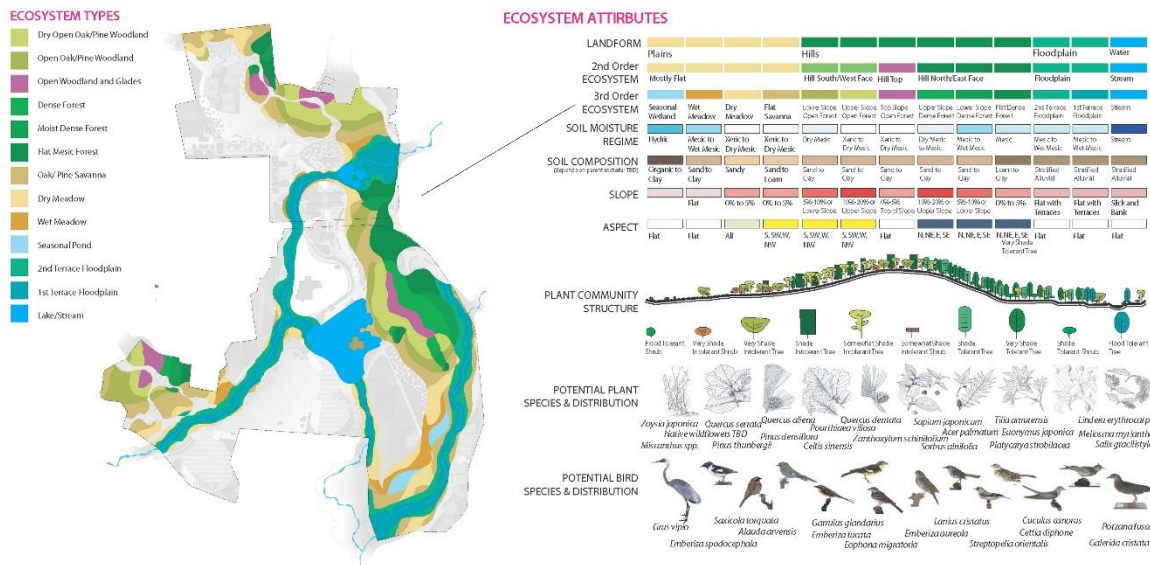


Figure 4: Example of ecosystem mapping of site-scale natural ecosystems based on the landscape ecosystem method by Barnes (1993).

In urbanized areas, ecosystem types may be characterized by combinations of remnant natural ecosystem characteristics, built features, and human processes (Pickett et al. 1997). Since urban ecosystems are significantly influenced by human processes, classification requires special attention to socio-cultural, economic, and other human patterns and processes (Pickett et al. 1997, Grimm et al. 2000, Opdam et al. 2013, Pincetl 2015). An important conceptual framework for understanding and classifying urban ecosystems, the human ecosystem framework, has been used as a theoretical basis for integrating human dimensions in urban ecosystem models and mapping over the past two decades (Machlis, Force & Burch 1997). The framework builds upon traditional ecosystem approaches by adding “social” and “built” complexes to account for key urban ecosystem properties. For example, demographic patterns can be overlaid with urban landscape patterns to identify relationships between supply and demand for ecosystem services, health, or stresses (e.g., PlanNYC 2011). Pickett et al. (2011) characterized human processes acting on urban ecosystems by partitioning areas by census block and classifying dominant “Lifestyle Types” of residents, which they found to be the best predictor of vegetation cover structure and tree canopy on private lands and right-of-ways. As has been discussed previously, perception, and the desire for cultural ecosystem services, such as recreation, aesthetics, or buffers are key drivers of urban landscape pattern and structure (Nassauer 2012, Termorshuizen & Opdam 2009). Municipal boundaries, built land use types, zoning, and ownership boundaries are also integral built and human factors for partitioning types because such boundaries often represent the jurisdictional reach of managers in urban areas.

### **A Nested Hierarchy of Ecosystems**

Ecosystems are often classified and mapped at multiple spatial scales in a nested hierarchy. An example is the system of ecological units developed by the USDA Forest Service for the United States in 1993 (Cleland et al. 1997). The system breaks the nation into increasingly fine-scaled tiers in a hierarchy including Ecoregions, Domains, Divisions, Provinces, Subregions, Sections, and Subsections. Each tier is intended to delineate areas of relatively similar ecological conditions to support management applications at a particular extent, from national applications (organized around Ecoregions) to more local applications (organized around Subsections). Figure 5 presents the USFS ecological units classification hierarchy for the area encompassing Los Angeles. The finest scale tier, “subsections”, have extents on the order of 100,000’s of thousands of acres<sup>2</sup> and are partitioned primarily based on combinations of seasonal climate patterns (air), physiography (earth), and vegetation cover types (biota/landcover) (McNab et al. 2007).

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<sup>2</sup> The imperial measurement system is used throughout this essay since it is the local convention in the Los Angeles case study region.



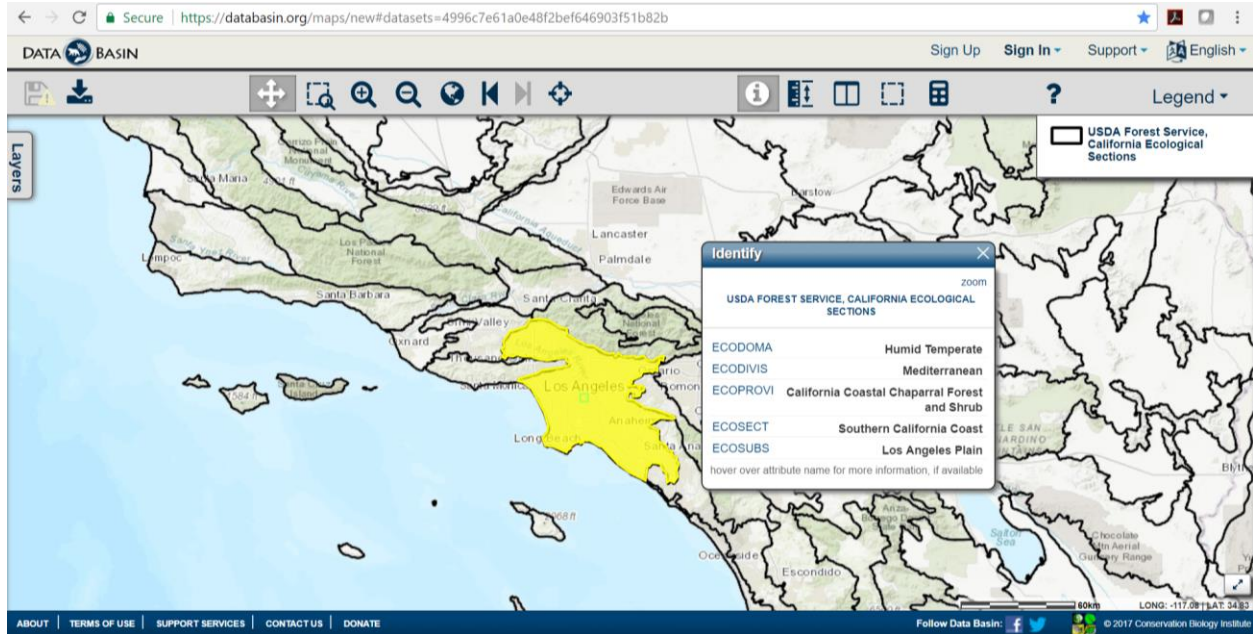


Figure 5: USDA Forest Service Ecological Units System (Cleland et al. 1997, McNab et al. 2007).

Many scholarly research efforts have involved mapping properties of urban ecosystems at multiple spatial scales, usually to answer relatively narrow questions such as the role of site climates contributing to urban heat islands or understanding urban forest carbon cycling mechanisms (e.g., Zhang et al. 2013). More complete classification and mapping of urban ecosystems from regional to site-scales, with an emphasis on comprehensive management rather than scientific research, has rarely been performed (e.g., Plan NYC 2011, McPhearson et al. 2013). The conceptual approach outlined below is intended to map urban ecosystems with the central goal of supporting urban ecosystem management by municipalities, non-profits, or other agencies. It proposes creating a nested hierarchy of urban ecosystem types at increasingly fine spatial scales using the US Forest Service's Los Angeles Plain Subsection as the starting point. The proposed hierarchy includes three increasingly detailed levels within the Subsection, "urban subregion," "neighborhood," and "site"-scale levels (see Figure 6).



Figure 6: USDA Forest Service Ecological Subsections of Southern California and proposed additional finer-scale hierarchy levels within the Los Angeles Plain Subsection (McNab et al. 2007).

## An Urban Ecosystem Typology Concept for Los Angeles

The following sections present conceptual urban ecosystem types and maps for Los Angeles. While these are potentially effective classifications "as-is", more detailed formal analysis would likely result in modified classifications, mapping, and boundary locations. Also, descriptions of

types would be expanded in a formal characterization to address each of the four urban ecosystem management themes. Figure 7 provides some examples of “ecosystem properties” that may be considered when characterizing types at each scale. Underlined properties denote those that were considered in the preliminary typology mapping for Los Angeles presented in Figures 8-11. Further evaluation of the relationships between properties and urban ecosystem management themes, available of data, and the local management context are necessary to optimize selection of properties for application.

|                          | Subregional-Scale Properties           | Neighborhood-Scale Properties  | Site-Scale Properties   |  |   |   |
|--------------------------|--|--|---|--|---|---|
| <b>Atmosphere</b>        | Temperature                            | <u>Seasonal Temperature Trends</u><br><u>Continental/Ocean Influence</u><br>Urban Heat Island Pattern<br><u>Cloud/Fog Prevalence</u> | <u>Frost/Freeze Prevalence</u><br><u>Maximum Daily Temp.</u><br>Extreme heat days   | <u>Elevation Influence</u><br>Evapotranspiration<br><u>Urban heat hotspots</u><br><u>Aspect</u>    | <u>Shading</u><br>Solar Intensity<br>Surface Reflectance/Absorption   |   |
|                          | Precipitation                          | <u>Seasonal Precipitation Trends</u><br>Orographic Enhancement<br><u>Rain Shadow</u>   |   |  | Rainfall intercept (vegetation)<br>Building rain shadow   |   |
|                          | Wind / Airborne Transport              | Pollution Transport<br>Ozone Formation   | Urban heat island   | <u>Criteria Air Pollutant Emissions and Exposure</u><br>Wind corridors<br>Wind direction/intensity | Sea Spray   | Wind exposure   |
| <b>Biota / Landcover</b> | Vegetation Cover / Species Composition | Dominant Vegetation Type<br>Growing Season<br>Dominant Plant Species<br>Indicator Species  | <u>Vegetation Structure</u><br><u>Subregional Connectivity</u><br><u>Landscape to Area Ratio</u><br>Landscape Patch Density<br><u>Historic Native Plant Community</u> | Stem Density<br><u>Canopy %</u><br>Indicator Species   | Landscape Patch Size<br>Local Connectivity<br>Landscape Patch Shape<br>Biomass  | Structural Layers<br><u>Species composition</u><br>Canopy height<br>Indicator Species<br>Invasive Species |
|                          | Built / Social Complex                 | Urban Transect Position (Urban, Suburban, Periurban, Exurban)<br>Land Use Matrix/Pattern   | <u>Residential Density/FAR</u><br>Perception/Behavior<br><u>Parking/Hardscape Area</u><br>Street Width/Density<br><u>Solar Reflectance Index</u>                      | <u>Land Use Type</u><br>Building Area<br><u>Building Height</u><br><u>Building Spacing</u>         | Cultural Behavior<br>Landscape Maintenance/Stewardship<br><u>Building Shadow</u><br><u>Rainwater Capture/Conveyance</u> |   |
| <b>Physiography</b>      | Landform / Hydrology                   | <u>Landform</u><br><u>Hydrologic Regime</u>  | <u>Aspect</u><br>Slope %<br><u>Elevation</u><br>Watershed Orientation   | <u>Flood Regime</u><br><u>Wildfire Regime</u>  | <u>Groundwater Depth</u><br>Slope Position<br><u>Site Aspect/Orientation</u><br><u>Flood Depth</u>                      |   |
|                          | Soil / Surface Properties              | <u>Soil Parent Material</u>  | <u>Soil Structure/Grading</u><br>Soil chemistry<br>Erosivity<br><u>Solar Reflectance Index</u><br>Heat Absorption Capacity  | <u>Soil Moisture regime</u>  | Groundwater Influence<br><u>Toxic Contamination</u><br><u>Surface Permeability/Drainage</u><br><u>Soil Profile</u>      |   |

Figure 7: Example urban ecosystem properties used for characterizing ecosystem types at multiple spatial scales. Underlined properties denote those considered in conceptual urban ecosystem types for Los Angeles.

### Urban Subregion-Scale Urban Ecosystem Types

In urban planning practice, an urban “subregion” typically refers to an area on the order of 10,000’s to 100,000’s of acres. This unit is often considered in large-scale urban planning contexts such as major infrastructure, “general plans” in U.S. cities, or for exurban growth planning common at the urban fringe for cities around the world. Subregions are useful for applying broad-brushed ecological objectives and frameworks, or understanding overarching ecological drivers such as microclimates, major landforms, ecological hazards, or land use context.

Preliminary subregional ecosystem mapping for the Los Angeles Plain in southwestern L.A. County is presented in Figure 8. Typologies and partitions are based largely on a combination of microclimate and landform properties. Historical and current soil and landform maps, and Sunset Climate Zones for Los Angeles, were considered as the basis for landform and microclimates, respectively; however, more formal scientific mapping of Los Angeles

microclimates is needed (Bureau of Soils 1903, USDA 2017, Sunset 2017). General land use intensity (i.e., urban core, suburban, periurban, exurban, etc.) or land use types could also be considered in classification at this scale for many cities. However, since the L.A. Plain is intensively developed across almost its entire extent, and does not strongly exhibit a typical urban transect of reducing density from urban core to exurban fringe, land use intensity and types are instead considered in the neighborhood-scale classification in this case. Despite the development intensity, landform and microclimate are still dominant natural ecosystem features in the subsection, with important implications on urban ecosystem management. Landforms in L.A. have distinct soil properties and topography with implications for stormwater management, groundwater recharge, vegetation, and ecological hazards such as riparian flooding, sea level rise, and wildfire. Microclimates are extremely diverse in L.A., and are key drivers of urban biodiversity, ecosystem function, and landscape character. Boundaries for this classification generally follow landforms of the Los Angeles Plain, except for the southeastern boundary which follows the Los Angeles County Line.

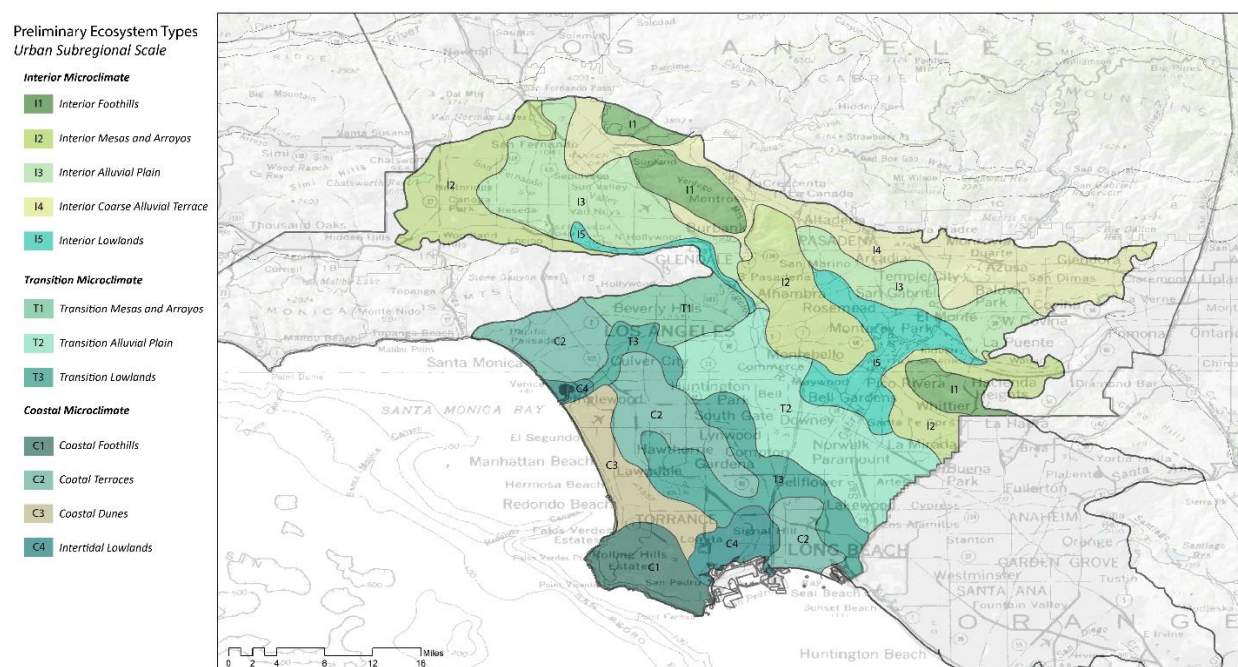


Figure 8: Conceptual subregional-scale urban ecosystem types of the Los Angeles Plain Ecological Subsection of Los Angeles County considering landform and microclimate factors only.

### *Neighborhood-Scale Urban Ecosystem Types*

The “local scale” (i.e., neighborhood scale) has been described as key for producing actionable science and tools to support urban ecological decisions (Opdam et al. 2013, Kaczorowska et al. 2016, Kramer et al. 2016). This has also been my professional experience, with most urban ecological decisions executed through design of individual sites, infrastructure features, neighborhood-scale urban design, or community masterplans. Subregional and larger-scale analysis at coarse resolutions are often of more limited value beyond support for broad brushed policies, providing contextual information, or as city-wide ecosystem organizing frameworks.



Figure 9: Neighborhood Urban Ecosystem Map. The approximate east-west extent is 7 miles.

Figure 9 delineates example neighborhood-scale urban ecosystem types based on a combination of land use and landform boundaries relevant to the four management themes. Neighborhood ecosystem units range in size from 10's to 1,000's of acres. This area in South Los Angeles straddles the two subregional-scale types, Transition Alluvial Plain and the Coastal Terrace Subregion. Neighborhood-scale naming conventions include reference to land use type and intensity, (e.g., dense urban mixed use), landscape character (e.g., savanna or barren to indicate level of tree canopy and relative area of landscape vs. built), air pollution exposure (e.g., high or low), and ecological hazard exposure (e.g., riparian to indicate types partitioned based on the Los Angeles River flood profile). Neighborhoods in the eastern portion of the area (right) include high levels of air, water, and soil pollution and limited landscape area. Management of regulating ecosystem services to provide mitigation and remediation of pollution may be a priority here. Neighborhoods in the west (left) are less constrained by hazards or pollution, and biodiversity enhancement, provisioning ecosystems services (e.g., urban agriculture), or cultural ecosystem services (e.g., learning gardens, aesthetic landscapes) may be more suitable management activities. Of course, management priorities would ultimately be subject to the local economic, cultural, and perception sensitivities of local decision makers and stakeholders. Such sensitivities (i.e., social properties) could also be used to refine urban ecosystem types and boundaries.

Additional photo examples of neighborhood types and naming conventions across a variety of subregions are presented Figures 10. These examples also address soil disturbance, including history of mass grading or fill material (“lost”), relatively ungraded but covered by built features (“transformed”), or “intact”, which could impact management of native plant species potential, stormwater management, or flooding. Type descriptions also address building density and height (e.g., urban canyon, deep urban canyon, suburban canyon, suburban, etc), which indicate building shade and area of landscape, potentially important variables driving plant species composition, biodiversity, and ecosystem services potential such as area available for tree planting.



**Figure 10: Conceptual Neighborhood Urban Ecosystem Types:**

*TL: Interior Mesas & Arroyos Subregion; Suburban Residential Savanna, Intact Soils, Moderate Pollution Exposure*

*TR: Coastal Terrace Subregion; Urban Residential Woodland, Intact Soils, Low Pollution Exposure*

*ML: Interior Mesas & Arroyos Subregion; Suburban Residential Canyon Savanna, Transformed Soil, Fire Hazard, Low Pollution Exposure*

*MR: Intertidal Lowland Sugregion; Urban Canyon Forest, Transformed Soils, Coastal Flood Hazard*

*BL: Transition Alluvial Plain Subregion; Urban Industrial Barren, Lost Soils, High Pollution Exposure, Riparian Flood Hazard*

*BR: Transition Alluvial Plain Subregion; Deep Urban Canyon Forest, Lost Soils, High Pollution Exposure*

### *Site-Scale Urban Ecosystem Types*

Figure 11 includes a conceptual site-scale urban ecosystem profile for an individual residential parcel. It includes a description of the urban ecosystem context, and opportunities and constraints for urban ecosystem management. It also includes a map of site-scale ecosystem types within the surrounding neighborhood. Proposed site-scale ecosystem units range in size from 10's of acres to less than an acre. These types are largely driven by parcel orientation (an indicator sun exposure, shade, and plant species suitability), soil type (an indicator of plant species suitability, stormwater infiltration, and level of site disturbance), surrounding landscape pattern and connectivity context (e.g., riparian corridor and distance from major urban habitat patch, indicators of urban biodiversity or flood risk). Such profiles could provide guidance for

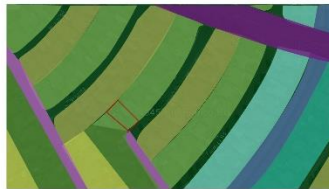
sites that aligns them with broader-scale management objectives such as: supporting subregional urban habitat connectivity; optimizing ecosystem services strategies like tree planting to cool urban heat island or air pollution hotspots; or implementing distributed infrastructure to protect vulnerable sites from flood risk such drainage swales or protective berms in residential landscape areas.

**Residential Parcel: Parcel ID, Address**



**Site Ecosystem Map**

- Residential Parcels- Southeast Orientation
- Residential Parcels- Northwest Orientation
- Residential Parcels- Northeast Orientation
- Residential Parcels- Southwest Orientation
- Arterial ROW with Median- North/South Oriented
- Residential ROW- Northwest/Southwest Oriented
- Residential ROW- Northeast/Southeast Oriented
- Residential Parcels- Riparian Edge Northwest Orientation
- Residential Parcels- Riparian Edge Southeast Orientation
- Channelized and Sealed Urban Stream



**Urban Ecosystem Description**

**Subregional Ecosystem Description**

*Coastal Transition Valleys & Terraces:* moderately hot summers, moderate marine influence, high priority habitat connectivity zone, air pollution receiving zone, moderate urban heat island.

**Local Ecosystem Description**

*Suburban Savanna Terrace, Medium Low Density:* South to Southeast Aspect, Gentle Slopes, Intact Native Soils, Single Story Structures, >50% landscape, <10% canopy, Moderately Poor Air Quality, Low Heat Island Contribution, Coastal Sage Scrub/Riparian Savanna Historic Ecosystem Types.

**Site Ecosystem Description**

*Southeast Oriented Residential Parcel, Intact Soils:* 0.15 acres, Loamy Clay Soils, Southeast Aspect, Frost Pocket (1 to 3 frosts per year), 2-9% slopes, 25% shaded, 90% turf/10% mixed shrubs, 2.5 miles to nearest major habitat patch, 0.7 miles to park, moderately poor air quality, high runoff.

**Urban Ecosystem Health Enhancement Opportunities & Constraints**

| Indicator Category                | Enhancement Measures                            | Priority Level |
|-----------------------------------|---|----------------|
| Hydrology/Water Quality           | Provide bioswales                               | High Priority  |
| Urban Heat Island/Climate Control | Low albedo roof materials                       | Low Priority   |
| Native Biodiversity               | Coastal Sage Scrub highly suitable              | High Priority  |
| Habitat Connectivity              | Include habitat stepping stone                  | High Priority  |
| Invasive Species                  | Minimal threat to natural areas                 | Low Priority   |
| Landscape Carbon Cycling          | Large, long lived, low maintenance trees        | Low Priority   |
| Ecological Hazards                | Minor street flooding                           | Low Priority   |
| Toxic Contamination               | 1.1 miles to toxic emitter                      | Low Priority   |
| Air Quality                       | High receiving location for criteria pollutants | Low Priority   |
| Parks/Open Space Accessibility    | 0.7 miles to nearest park                       | NA             |
| Aesthetics/Community Enrichment   | Promote alternative landscapes to lawn          | High Priority  |

Site Notes: **High Priority Location for Ecosystem Enhancement**

Figure 11: Conceptual Site-Scale Urban Landscape Ecosystem Profile

**DISCUSSION**

Creating comprehensive, spatially explicit, and well-articulated urban ecosystem frameworks that effectively incorporate human ecosystem dimensions is challenging across broad extents, high resolutions, and diverse urban contexts. Efforts may be worthwhile, however, as such frameworks and associated typology classifications are powerful tools for improving effectiveness and integration of increasingly important site-ecology considerations in urban management decisions (Haase et al. 2014, McPhearson, Kremer & Hamstead 2013, Chan et al. 2006, De Groot et al 2010, Seto et al. 2012). Maps and typologies provide a platform for communicating and coordinating the structure, pattern, and functional properties of urban ecosystems to support optimizing the benefits and impacts of management. Given the interconnected nature of ecosystems, and extent of many urban environmental challenges, coordinating projects across disciplines, sites, and scales is critical to enhancing urban resiliency and sustainability objectives. Diverse socio-cultural dimensions also present a unique challenge for urban ecosystems ranging from aligning management goals with cultural sensitivities, to the intense competition for use of urban land. Methods for considering such human dimensions in urban ecosystem frameworks is a key area of further study.

In addition to coordinating and informing site decisions, typologies can also be useful in measuring ecosystem health and services relative to other ecosystems or areas, which is important in many management contexts (McPhearson et al. 2016, Costanza and Magneau 1999). Such “benchmarking” provides useful points of reference for understanding ecosystem functions, comparing management performance, or setting performance objectives across types. Comparing ecosystem health of neighborhoods, watersheds or other extents within cities for prioritizing and optimizing management activities are likely useful applications of this concept. Comparing a site’s historic conditions with its current urban condition is another potentially useful benchmarking approach that can reveal unique ecological management opportunities and constraints (see example in Figure 12). In professional urban design and landscape architecture projects, historic ecology often informs design by inspiring creative expression, revealing environmental opportunities for site engineering, or setting ecological performance targets such as achieving natural runoff rates or landscape carbon stock at least equal to the natural condition (i.e., “landscape carbon footprint neutral”).



Figure 12: Temporal ecosystem benchmarks for the Anaheim Regional Intermodal Transportation Center site, Anaheim, CA, USA. Percentages are conceptual representation of ecosystem services potential relative to the “ecosystem services minimum” in 1975.

Creating urban ecosystem typologies and maps for cities requires robust data and may be completed using a variety of data analysis techniques. Modifying existing research-oriented ecosystem models and methods as management tools may provide useful analysis platforms. For example, Lehmann et al. (2014) proposed methods to classify urban vegetation structure types including soils, microclimate, and building characteristics at the site-scale. Stewart and Oke (2012) produced a method of classifying “local climate zones” for use in urban heat island modeling based on urban landscape, building, and landcover properties. The USDA Natural Resource Conservation Services provides detailed soil survey maps for cities that include robust physiographic characteristics (e.g., USDA 2017). Integrating socio-cultural properties in urban ecosystem mapping is an key area of further research, but census data provides basic information at the census block or tract-level.

Together, the ecosystem properties classified in the above examples represent many of the air, earth, and biota/landcover layers that may be aggregated to delineate urban ecosystem types. Existing potential models for aggregating data into types include HERCULES (maps landscape heterogeneity based on land cover — see Zhou et al., 2016) and HPM-UEM (multi-scaled urban ecosystem pattern/structure model — see Zhang et al. 2013). Alternatively, the more traditional overlay method pioneered by Ian McHarg may provide a simpler, yet effective, approach to aggregating data into typologies, and is still an often-used technique in urban planning practice today (McHarg, 1971).

Considering more traditional ecosystem mapping methods and lessons learned over decades of application in natural lands is also important to consider as new urban applications are developed. Many newer models and methods rely on increasingly high resolution remote sensing data that has the potential to improve measurement of urban ecosystem properties. However, Kandziora, Burkhard & Müller (2013) point out that most recent urban ecosystem services studies rely on remotely sensed data at a reduced level of detail and precision compared to more traditional field-based sampling methods. Considering older field-based ecosystem inventory methods may also provide important insights and increased effectiveness of new approaches (Kramer et al 2016). However, the emergence of drones, LIDAR, and street level remote sensing (e.g google street view) and other higher resolution products are improving the quality of remotely sensed data, yet higher cost and computing power requirements can also become prohibitive.

## CONCLUSION

Cities worldwide are reshaping their urban ecosystems, often under the banners of sustainability and climate change resiliency initiatives. Along the U.S. West Coast, cities from Los Angeles to Seattle are increasing urban population density while investing heavily in sewer and stormwater systems with large green infrastructure components to meet long overdue water pollution performance standards (e.g., SFPUC 2013, NYC 2016). Because of drought and climate change, the Los Angeles region has invested hundreds of millions of dollars to replace lawns with water-efficient landscapes, which is changing the character of neighborhoods, microclimates, and water supply infrastructure. L.A. and San Francisco have recently embarked upon city-wide efforts to enhance urban biodiversity and ecosystem services to provide cultural and nature benefits. Countless cities are developing plans to alter urban ecologies to accommodate climate hazards including sea level rise, extreme urban heat events, and changing flood regimes. Urban ecosystem-based frameworks are well suited to comprehensively address these profound and complex urban ecological challenges. First, however, as Pickett et al. (1997) point out: “understanding how urban ecosystems work, how they change, and what limits their performance” are key for optimizing management and enhancement strategies (Haase et al. 2014). Comprehensive, place-based ecosystem frameworks, supported by tools like urban ecosystem typologies and shaped by the needs and conventions of on the ground decision makers, represent a promising step toward improving this understanding and addressing these pressing urban challenges.

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