Title: Defining the Urban Rules of Life To Design Sustainable and Healthy Cities

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Audience: Biologists, Landscape Architects, Civil & Environmental Engineers, Planners

Goal: The question in playground 6 could be rephrased: "What can we learn about the rules of life by studying the response of biological systems to direct and indirect human manipulation?" Cities contain vast and numerous natural experiments, as newly emergent and human-constructed urban environments rapidly expand across the world, displacing, fragmenting, and transforming naturally-occurring and ancient ecosystems. Given the opportunity to engage a broad audience - from basic researchers to teachers, civil engineers and concerned citizens - studying the translation of the rules of life onto the urban landscape would naturally create an integrative and cross-cutting set of questions and hypotheses that would be relevant for the design and management of sustainable and livable cities in the future.

Broader Impact: Research on urban environments provides the opportunity for authentic field-based experiences in biology for underserved communities in cities which are directly relevant to their well-being.

Introduction

Biomes around the world respond to rapid environmental change in different ways, from high latitude tundra to equatorial rainforests. Understanding the different ways in which these biomes respond could elucidate important aspects of how communities respond generally to rapid change. Over the past century, humans have played an increased the rate at which we are modifying and changing natural ecosystems for our own purposes. The urban biome is a novel and dynamic environment that presents a complex mixture of constructed and natural areas that are often a novel challenge to biological organisms.

Globally, the majority of people live in cities, and the trend toward urbanization continues to grow, in expanse and density. Cities are also changing rapidly, as architecture and technologies change, urban human cultures change, and climate change dramatically impact the urban environment. Rates and patterns of growth and change vary considerably across continents and cultures, with brand new construction and development of urban infrastructure occurring rapidly in 'The Global South' while older cities have a stable core with a rapidly expanding suburban and peri-urban population. In many European and North American cities, population levels have increased less explosively, but never-the-less increase as country rural residents move to cities and immigrants preferentially settle in cities. These contrasting histories provide the opportunity for informative and powerful comparisons across temporal and spatial patterns. The urban biome also remains connected and networked with the larger built landscape that supports industrial and agricultural production and natural areas with its regional biodiversity.

These interactions are an additional spatial component and interface between biomes that can be examined from the perspective of basic discovery. At present, there is a small and growing contingent of urban scientists that are investigating questions related to characterizing environmental conditions in cities, cataloguing what kinds of plants and animals inhabit urban areas, identifying the characteristics of species that inhabit cities, and understanding how these species distributions are associated with city design, history, and cultural practices. Connecting these efforts across disciplines can address more fundamental questions that can create predictive rules and concepts for more robust construction of these environments.

Defining the urban rules of life of this newly emerging novel biome will allow a deeper insight and understanding into the more general rules of life. Because the urban biome is typically harsh and extreme for many organisms and constructed for human purposes, large scale experiments are possible with the integration of relevant biological research and fundamental scientific endeavors into urban planning and development, within and among global cities. These human-constructed environments contain mixed assemblages of species, including those selected intentionally to provide ecosystem and aesthetic services while other organisms spontaneously colonize and naturalize to cities. Some of these colonizing organisms arrive from the surrounding peri-urban and natural landscapes while others are exotic species that are commensal with humans in cities around the world.

Our vision is that integrative biology can provide tools and concepts for designing sustainable cities, based upon a deep understanding of these urban rules of life. Human well-being will increasingly benefit from the construction of infrastructure that enhances and creates stable and equitable ecosystem services. Integrative urban natural systems research will naturally involve a broad range of scientific expertise and disciplines, from human health to civil engineering, from community ecology to plant breeding, and create opportunities for engaging citizens in the observation and documentation of their living environment, and the training students and professionals in basic and applied research. This vision also directly addresses and raises a number of challenging ethical and cultural questions about the intentional manipulation and control of nature which is a great improvement over the current accidental and haphazard construction of these environments based upon short-term development goals.

Defining Urban Rules of Life

Just as with other characterizations of biomes, there are multiple factors along a continuum of human-altered environments that contribute to habitat being considered “urban.” For example, Faeth et al. (2011) recognized that metrics of urbanization differ across urban biodiversity studies “may be based on human population density, economics, dwelling density, or amount of paved surfaces, and may vary by spatial scale.” By defining the Urban Rules of Life, we seek to understand whether these metrics of urbanization lead to “rules” governing urban environments that differ from those in non-urban, or natural, environments. Are the “Urban Rules of Life” unique and distinct from the “Rules of Life”? If so, can we learn anything about the impact of human manipulation, direct and indirect, on the evolutionary potential of urban ecosystems and the species that exist within them? Can we learn how to better control and manage the sometimes deleterious commensals that are ubiquitous in urban environments?

As a starting place, we should leverage frameworks developed for natural ecosystems to study urban species and communities. What aspects of natural ecological and evolutionary processes affect these artificial constructs or niches created both intentionally and accidentally by humans? When creating purposefully built urban ecosystems, can we leverage knowledge of traits of currently successful urban species to engineer similar traits into species threatened by increased urbanization?

Biodiversity in Time and Space

- What species occur in urban environments? Do they share common traits?
- How do the age and size of cities impact species?
- How do vertical structures and surfaces impact species diversity?
- Do urban environments exhibit a latitudinal diversity gradient?
- What are common traits of cosmopolitan commensal species?
- Are urban species richness and abundance patterns (e.g., dominance diversity curves) similar to those for natural ecosystems?
- How do we restore “wild” species in novel urban environments?
- Do the principles of island biogeography apply to the island and archipelago geography of urban landscapes?
- What is the landscape ecology of population and gene flow among sectors of a city and between a city and the peri-urban landscapes?

Ecosystem Structure and Function

- Do urban environments contain analogs of natural environments?
- Are there uniquely-urban microbial communities that provide ecosystem services to the urban biome?
- How are species distributed spatially (including vertically) in urban environments?
- What are functional traits common to urban species?
- Are specific functional traits missing from urban species because of a lack of ability of species with those traits to colonize urban environments?
- How do species communities differ between urban environments that grew at different rates (gradual vs. “spontaneous”)?
- Do urban ecosystems exhibit similar patterns of edge and boundary effects?
- How does the potentially more extreme spatial heterogeneity in environmental characteristics (e.g., temperature, humidity, substract) impact species composition and interaction?
- What is the impact of linear transportation infrastructure that connect cities to one another as well as cities to non-urban landscapes?
- How do urban biomes interact with surrounding periurban and natural landscapes?
- How will global climatic change impact communities and ecosystem functioning in urban biomes?

Evolutionary Processes

- What members of the urban ecosystems are reproducing sustainably versus persisting by repeated colonization or introduction?
- How is gene flow mediated within and between urban biomes?
- Do novel urban microhabitats facilitate the evolution of traits not found in non-urban environments?
- How do urban organisms adapt to rapidly changing urban environments?
- Do urban species exhibit niche conservatism (e.g., seeking out microhabitats similar to the "natural" niche) or do they colonize and/or adapt to novel microhabitats?
- Is peripatric speciation more common in urban environments?

Physiology and Behavior

- Are seasonal and climatic changes buffered or intensified by the urban environment and how does this affect biological organisms and communities?
- Is the exposure to physiological stressors and tipping points greater in urban environments and how does this vary spatially?
- Does the distribution and connectivity of urban habitat types allow biological organisms to go through all of their life history stages? (are all necessary types available?)
- How are interaction networks across trophic levels affected?
- To what extent does physiological plasticity facilitate adaptation to variable urban environments?
- How do homeostatic effects of different degrees of urbanization impact native and non-native species in urban communities?
- How does nutrient availability impact patterns of growth and maturation in urban biomes?
- Are there cognitive adaptations to urban life by animal species for dealing with humans and with the dynamic, rapidly-changing infrastructure and technologies within cities?
- Do plants and animals shift phenologies and circadian rhythms to adapt to environmental conditions of cities?

Applications of Urban Rules of Life Research on the Urban Biome

Urban Rules of Life research integrates biology from the molecular level of physiology and evolutionary change through the level of organismal physiological and behavioral traits and on to community and ecosystem ecology. It is interdisciplinary, integrating domains of human social and behavioral science and engineering and architecture. Therefore, the applications are broad, and we anticipate novel topics to emerge as biologists, other scientists and engineers, social scientists, psychologists, humanists, and citizens in general indicate what is important. As much as any field, urban rules of life research reflects human cultural values and ethical concerns.

To give some form to our vision, we propose some initial research priorities for urban rules of life research. We are certain that readers will identify others that are equally compelling questions.

Scientific Questions of Urban Rules of Life Research

- How do individuals acclimate and species adapt to novel environments and interacting species?
- Is there a syndrome of physiological, life-history, ecological and behavioral traits associated with urban biome species?
- Is there a form of urban biome succession, with explicable differences between pioneering urban life and organisms that colonize cities later?
- How do urban organisms evolve and adapt to environmental change in cities (climate, technological, architectural, and cultural change)?
- Does urban species' and urban biomes' evolution and adaptation occur at the same rate as the changes in architecture, technology, and culture in cities?
- In what ways and with what traits does microbial life sustain the urban biome?
- What is the role of niche construction in sustaining populations of urban species?
- Can we identify and quantify ecosystem services provided by urbanized species and the urban biome?
- Can we apply urban rules of life thinking to understand and control epidemiology of pathogens in urban environments?
- Given that urbanization itself is a process and continuum, do traits important to urbanization change along that same continuum (e.g., are the rules of life different in the suburbs?)
- What are the urban landscape configurations that make it easier or harder for biodiverse urban biomes to be sustained?
- Are there predictable differences in urban biome structure and function depending on geographic or cultural history, economics, demography, or city age?

Answering the questions above will allow us to understand the fundamental urban rules of life, and how these vary among cities and along gradients of urbanization. This will provide the knowledge to apply toward designing and managing cities' urban biome for the benefit of people and other species.

Application of Urban Rules of Life Research

- Identify the unique challenges and opportunities to organisms in cities (physiologically, behaviorally, ecologically) so we can manage these effectively.
- Engineer (assisted evolution) both species and urban environments to maximize ecosystem benefit.
    - Engineer physiological traits of species that promote ability to survive in urban microclimate, chemical contamination, urban soil and water quality, and noise-light-human disturbance stress.
    - Engineer urban environments to inhibit colonization, control populations, and prevent evolution of unwanted pathogen and 'pest' species.

- Biotic surveys of urban environments along spectrum of urbanization continuum, including diversity of novel urban microhabitats
    - Baseline data on patterns of colonization of urban environments.
    - Understanding of urban phenology and spatial structure (including vertical stratification) of urban communities.
    - Leverage network of community scientists to monitor key urban taxa.
    - Evaluate whether species in urban environments occur in conditions similar to those observed for them in “natural” ecosystems (e.g., temperature, humidity, light) or whether they have adapted to novel conditions unique to the urban context.
- Predict what species will adapt well to urban environments.
    - Which species are more likely to become invasive?
    - What traits allow native species to cope?
    - How are species interactions modified, both negative and positive?
- Conduct global monitoring of cosmopolitan species that are present in urban environments across natural biomes to understand the impact of local environment on a common genomic/phenotypic background.
- Identify what ecosystem services are provided by organisms that can persist in urban environments.
    - Determine when a collection of trees begin to function as a forest and how these functions emerge
- Design configuration of land uses in cities that are needed to maintain healthy urban biomes (e.g., forests, wetlands)
- Re-engineer and restore ecological functions to urban streams and other water bodies.
- Promote or enhance urban niche construction and urban biome assembly.
- Enhance green architectural design with urban biome organisms that provide desirable ecosystem services.
- Educate civil engineers, landscape architects, an urban ecologists on opportunities and constraints on designing urban biomes.
- Incorporate human cultural differences in urban design.
- Promote and facilitate evolutionary processes in spontaneous communities that maximize sustainability and benefit.

Ethical & Cultural Considerations in Urban Biome Design

Successful design of sustainable urban biome environments must also include ethical and cultural considerations. Multiple questions arise when deciding *what* to enhance in a designed urban biome environment. These questions address potential ethical constraints at multiple levels, from what traits of an organism to engineer to the potential evolution and impact of urbanized species and ecosystems from one urban biome to another. How these questions are addressed will require the integration of a wide variety of expertise to interpret the goals of the urban biome design and the ethical decisions behind those goals. Due to the richness of cultural and biodiversity, one formula that can be applied for every urban biome design is unlikely to be the solution. The following are some of the variables and considerations that will have to be integrated in the design of future urban biomes.

What species to enhance?
One important goal clarification is whether urban biomes should be designed strictly for human benefit (ecosystem services) or whether the design should also prioritize conservation of native biodiversity for its own sake. A potential goal could be to design urban biomes to resemble the indigenous natural communities of the region. The problem arises when those native species cannot adapt to urban environments. To address those challenges, should exotic species that are better adapters or provide greater ecosystem services be favored? When considering ecosystem services, what aspects of ecosystem services should be enhanced in urban environments?

What traits to engineer?
The Integration of Biology allows for genetic engineering of new species that are designed specifically for urban biomes. This raises questions about the desirable traits that should be bioengineered in organisms. Should the goal be for organisms to better adapt to urban environments, or to enhance the ecosystem services they provide? One potential goal can be to bioengineer organisms that most resemble the indigenous natural communities of the region with added adaptation traits to urban environments. Alternatively, the goal can be for well-functioning urban biomes, regardless of the origin of the component species and the novelty of the resulting biome. The evolution (or predicted evolution) of these engineered organisms and the potential impacts within the designed urban environment and with neighboring peri-urban environments are important aspects that need to be included in the design. Further questions include whether we should control the flow of these urban ecosystems and species to either created isolated urban ecosystems or facilitate connection and interchange with peri-urban "natural" ecosystems?

How to Integrate cultural dimensions in the design?
One key question is how to integrate culture into urban biome design. To productively engage this question, understanding culture in terms of diversity of heritage and tradition as well as a framework for how residents make sense of their surroundings is critical. This focus on sense-making draws our attention to questions of how different biome designs resonate broadly within urban populations. For example, an urban biome design that focuses on conservation of a culturally important species may help bring residents on board with design initiatives. Beyond these basic questions of cultural sense-making, we can also ask how cultural differences are integrated in the optimization of the urban biome design? Indeed, the cultural beliefs, traditions, and rituals of residents will significantly alter the design of what species and traits to enhance or engineer in urban biome structures. Questions of culture draw us even further into investigating deeply felt and widely accessible worldviews about how humans relate to the lived environment. For example, a predominant cultural worldview grounded in mastering one's environment may run counter to another worldview grounded in principles of adaptability. Within a paradigm of increased modernization and development focused on technological advances, these questions become increasingly important. Many cultural traditions articulate values focused on the importance of living in harmony with one's environment. In order to reach this level of integration, social scientists, psychologists, and leaders of the communities will be active

participants in the design. This integration raises challenges on how scientists communicate their goals to non-scientist. Culture and communication experts can facilitate this dialogue for optimal results.

How to design training programs?
A training program in urban biome design must bring together multiple disciplines that focus on a systems approach. This would include, at a minimum, engineers, urban ecologists, social scientists, psychologists, landscape architects, and biologists from all disciplinary areas. If the goal of a training program is to produce practitioners that are able to effectively engage in urban biome design, then an individual would need at least some exposure to all facets of integrated biome design. Of particular importance in these programs would be training in effective and culturally-sensitive communication. Thus, communication scholars that focus on science communication, environmental communication, and intercultural communication would be beneficial to a training program. From a science communication perspective, trainees would gain expertise in communication between scientists and the public. Environmental communication scholarship focuses directly on how communication processes impact the relationship between humans and the non-human world. This would provide trainees with a conceptual apparatus that is broadly inclusive of different approaches to urban design.

Suggested Reading

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