COMPLEXITY,

Cities That Think like Planets

RESILIENCE, AND

INNOVATION

IN HYBRID

ECOSYSTEMS

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Complexity, Resilience, and Innovation in Hybrid Ecosystems

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Cities That Think like Planets

Preface

My son's nightlight is a globe. Every evening at bedtime, he makes up a story about the origin of the planet or about its future. All of his stories are imaginary and, at the same time, grounded in his daily experience of living on the planet and in a beautiful city: Seattle. Children have the ability to identify with the world and the objects in it, to acknowledge what supports them, to see the world through many lenses, to tolerate ambiguities, to accept multiple explanations, to experiment with what is possible, and to exist simultaneously in many physical and mental spaces. These qualities are critical to humanity as a whole, if it is to succeed in creating a human habitat of the long now.

Cities now face an important challenge: they must rethink themselves in the context of planetary change. What role do cities play in the evolution of Earth? From a planetary perspective, the emergence and rapid expansion of cities across the globe might be another turning point in the life of our planet. Earth's atmosphere, on which we all depend, emerged from the metabolic processes of vast numbers of single-celled algae and bacteria living in the seas 2.3 billion years ago. These organisms transformed the environment into one where human life could develop. Can humans now change the course of Earth's evolution? Can the way we build cities determine whether we will cross thresholds that might trigger abrupt changes on a planetary scale (Rockström et al. 2009)? Can the rapid development and emergent patterns of urban agglomerations across the globe represent a tipping point in Earth's life, one on the scale of the Great Oxidation (Lenton and Williams 2013)? Will we drive Earth's ecosystems to unintentional collapse? Or will we consciously steer the Earth toward a resilient new era?

The challenge for urban ecology in the next decades is to understand the role humans play in eco-evolutionary dynamics (Post and Palkovacs 2009). Humans are not simply changing ecological conditions globally (Crutzen 2002; Vitousek et al. 1997); we are changing what Hutchinson (1965) called the ecological stage on which the evolutionary play is performed. From a planetary perspective, NASA's Visible Earth Night Lights images suggest an even more extraordinary story of urbanization: the planet and life are co-evolving, changing the courses of each other's histories (Frank 2013). If, as emerging evidence indicates, rapid evolution does affect the functioning and stability of ecosystems (Schoener 2011), current rapid environmental change and its evolutionary effects may have significant implications for ecological and human well-being on a relatively short time scale. Integrating humans into the study of eco-evolutionary feedback can generate significant insights to advance understanding of urban ecosystems' functions and lead to major revisions in the theories of ecology and evolution on a human-dominated planet (Alberti 2015).

A science of cities as coupled human-natural systems has yet to be developed. During the past few decades, we have learned a great deal about how urbanization affects ecological conditions (Grimm et al. 2008a; McDonnell and Pickett 1993; Pickett et al. 2011). Yet the complex mechanisms and feedbacks governing the dynamics of human-natural systems are poorly understood (McPhearson et al. 2016). We do not know how local interactions among human and biophysical processes shape the urbanization patterns of metropolitan regions or how emerging patterns affect human and ecological functions in urbanizing regions. Evidence from growing numbers of studies does indicate that we need to redefine the assumptions of traditional theories and methods in ecology and human sciences if we are to understand such complex dynamics (Alberti 2008; Grimm et al. 2008a; Pickett et al. 2013; Liu et al. 2015). Ecology has long excluded humans from ecosystem studies (Alberti et al. 2003). Thus, ecological experiments conducted primarily in pristine areas can offer designers and planners only limited scientific knowledge, except for the typical advice to keep humans out. By articulating testable hypotheses about the interplay between human agency and eco-evolutionary dynamics, urban ecology has a unique opportunity to advance ecological science and practice (Forman 2014).

In this book, I advance the hypothesis that cities are hybrid ecosys-

tems: the product of co-evolving human and natural systems. The hybrid city simultaneously serves social and ecological functions and is defined by complex interactions among these functions. I ask: What makes an urban ecosystem simultaneously resilient and able to change? Do urban ecosystems have generic properties or qualities that predict their adaptive capacity? What underlying mechanisms explain variation in their ability to self-organize and evolve? How can the science of complex systems help us tackle these questions? Emerging evidence in ecological and social systems indicates that when systems are heterogeneous (i.e., their components vary) and modular (i.e., those components are not entirely connected), they tend to be better able to adapt than those whose elements are homogeneous and highly connected (Scheffer et al. 2012). In hybrid ecosystems, resilience—their ability to adapt to changes—depends on the diversity of biological organisms and on social groups and the economic activities that coexist within them. These ecosystems entail a diversity of cultures and human values as well as the existence of conflicts. Modularity implies loose connectivity among components and network nodes, which allows autonomous functionality. Diversity and modularity support the system's self-organization and provide the flexibility necessary for change. Cross-scale interactions and discontinuities provide opportunities for innovation and point to ways that systems can change and evolve (Holling and Gunderson 2002).

Cities are where innovation has historically occurred. The key role that cities have played in the development of science and technology, and in the generation of inventions and innovations—intellectual and material, cultural and political, institutional and organizational—has been well documented by scholars in a diversity of disciplines (Angel 2012; Glaeser 2012). While rapid urbanization accelerates and expands human impacts on the global ecosystem, it is the close interactions of diverse people that make cities the epicenter of both social transformation and technological innovation (Bettencourt 2013). Yet innovation is tightly linked to the capacity of urbanizing regions to adapt and evolve in a changing environment. For human civilization to achieve its full potential, it is essential to place technological innovation and social transformation in the context of local and global environmental change.

Interdependence between human and ecological processes in cities creates unprecedented challenges for city planners and designers; at the

same time, it provides unique opportunities for innovation. This book provides a road map to uncovering the emerging patterns, functions, and dynamics of urbanizing regions. I explore how we can develop an understanding of multiple equilibria and regime shifts in urban ecosystems and how a new planning paradigm can account for these phenomena (Norberg and Cumming 2008). This shift in paradigms will require a new level of integration between the natural and human sciences (Liu et al. 2007a) and between science and design (Pickett et al. 2013) at multiple scales, from the human experience of place (Beatley 2010) to the regional (Forman 2014) and the global (Grimm et al. 2008a). I discuss lessons that urban designers and planners can draw from complexity theory and from the dynamic of coupled human-natural systems, their self-organization, emergent properties, and resilience. Resilient cities require both knowledge and imagination. Planning strategies become reverse experiments to learn how human-natural ecosystems can coevolve and succeed.

This book proposes a co-evolving paradigm: a view that focuses both on unpredictable dynamics in ecosystems and on social and institutional learning. It develops ecological principles of design and planning: adaptation, flexibility, resilience, and transformation. In the final chapter, I suggest that we need a new ethic: to "build cities that think like planets" so that we might face the challenge of positioning the city in the context of planetary change. For Aldo Leopold (1949), "thinking like a mountain" meant expanding the spatial and temporal scale of land conservation by incorporating a mountain's dynamics. I suggest that we build on Hirsch and Norton's (2012) idea of "thinking like a planet" to expand the time and space dimensions of urban planning to the planetary scale.

Cities are the product of natural and human history and evolution. But they are also the product of human imagination. In Italo Calvino's *Invisible Cities* (1974 [1972]), Marco Polo describes the city of Fedora to Kublai Khan. In his description, the city's museum contains crystal globes that hold miniature representations of the city that individual inhabitants might have developed but never did. Urban ecology, like the map of Kublai Khan's empire, should have room for both the "true" Fedora and the little Fedoras in the glass globes, "not because they are all equally real, but because all are only assumptions. The one contains what is accepted as necessary when it is not yet so; the others, what is imagined as possible and, a

moment later, is possible no longer" (ibid., 32). In this book, I propose that we can uncover the fundamental laws that regulate the hybrid city only if we link science to imagination so that we can discriminate between what is probable and what is plausible and learn how to achieve what is desirable for the future of our urbanizing planet.

In this book I ask: What futures are we unable to imagine? I argue that what might be beyond our imagination are cities in which humans are key players in nature's game; cities that bio-cooperate, not simply bio-mimic natural processes; cities that operate on planetary scales of time and space; cities that rely on wise citizens and not just smart technologies. These are what I call cities that think like planets. The emergence of a new urban science that aims to uncover universal rules of how cities work is key to envisioning such transformations. But science and data answer the questions that we are able to formulate. How can we expand our imagination to formulate new questions?

A Road Map

Chapter 1 asks the reader to imagine the future and explores how our imagination of the future can transform the way we live in the present. Building on ecology and evolutionary theory, I contend, in chapter 2, that it is cities' hybrid nature that makes them simultaneously unstable and unpredictable, and also capable of innovating. The chapter examines complexity, emergence, regime shifts, innovation, and resilience in urban ecosystems and the scientific challenges they pose to urban ecology and resilience science. Emerging findings and observations of ecological anomalies in urban ecosystems are difficult to reconcile within current ecological theories; so, as I indicate in chapter 3, they require a new paradigm that better explains patterns observed in urbanizing regions.

Uncertain future interactions between social and ecological dynamics call for a paradigm shift in urban design and planning. Urban ecosystems are qualitatively distinct from other environments. In such systems, change and evolution are governed by complex interactions among ecological and social drivers. In chapter 4, I investigate the emergent properties that characterize urban ecosystems by focusing on patterns (e.g., sprawl), processes (e.g., hydrology), and functions (e.g., flood regulation). I develop an analytic approach by which to examine complex interactions

between slow and fast variables that control critical transitions, regime shifts, and resilience. I articulate a set of hypotheses and a research agenda to explore relationships between emergent properties of hybrid ecosystems and their abilities to adapt and innovate.

Studies of complex systems have begun to uncover direct relationships between system structures and resilience. Change, whether gradual or abrupt, is integral to the way nature works. Chapter 5 articulates the hypothesis that variable patterns of urbanization and modular urban infrastructure may be key to cities' resilience. I challenge the assumption that any single optimal pattern of urbanization is consistently more resilient than any other. I use three examples—carbon, nitrogen, and bird diversity—to illustrate the complex relationships between patterns of development and key slow and fast variables that regulate ecological resilience. I suggest that policies and management systems that apply fixed rules for achieving stable conditions by optimizing one function at one scale may make the overall system vulnerable and eventually lead to its collapse.

Chapter 6 specifically focuses on eco-evolutionary feedback. Humans are major drivers of micro-evolutionary change, but, at the same time, completely novel interactions between human and ecological processes may produce opportunities for innovation. Understanding the mechanisms by which cities mediate evolutionary feedback provides insights into how to maintain ecosystem function on an urbanizing planet. To develop and test a theory of urban ecology and the role of cities on a planetary scale, we need to redefine our methods and experiments and rewrite our protocols for collecting and synthesizing data.

In chapter 7, I propose that we define strategies as reverse experiments through which we can learn how urban ecosystems function, co-evolve, and succeed. Yet refining methodologies for studying urban ecosystems does not eliminate the complexity inherent in the fact that our knowledge is inevitably incomplete and that incompleteness, uncertainty, and surprise play a large role in the evolution of scientific thinking and decision-making. We must expand our ability to access multiple and diverse sources of observation and knowledge, as I discuss in chapter 8.

I attempt a synthesis of theory and imagination in chapter 9, where I suggest that by navigating through time, we can uncover our biases about what we know and challenge the idea that there is an end to dis-

covery. I also propose that we can learn from the future: if our cities are to be resilient on a planetary time scale, we must expand our horizons of time and space as well as our ability to embrace change. This chapter discusses the implications of complexity and uncertainty for framing management strategies for the cities of the future, and it articulates a series of principles for urban planning and design.

A Note on Style

The book focuses on the idea of cities as hybrid ecosystems. It is grounded in the science of urban ecology, but it aims to speak to a larger audience of urban designers and planners—and, potentially, to readers outside those fields—about the principles that can transform the way we see and build cities. I see the book as an extended essay: while it seeks primarily to contribute to the science of cities, it develops in several writing styles, ranging from fiction to scientific writing. Chapter 1, for example, describes four fictional images of the future city, while the style of chapter 6 is closer to that of a scientific article. By using these different approaches, I intend to make concepts accessible to a range of readers while maintaining a unified storyline. Each chapter contains explicit cross-references to other chapters, but chapter 10 is the one that brings together all of the book's diverse elements.

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