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Heterogeneity in Urban Ecosystems: Patterns and Process

LARRY E. BAND, MARY L. CADENASSO, C. SUSAN GRIMMOND,
J. MORGAN GROVE, and STEWARD T.A. PICKETT

Abstract

Heterogeneity in urban ecosystems derives from a combination of natural and engineered landscape features, as well as behavior of human individuals and institutions. Modern urban regions in North America and elsewhere are no longer uniformly compact and densely populated but have extended into surrounding regions and include intricate mixes of residential, commercial, and residual agricultural, forest, and other managed and unmanaged vegetated areas. Compared to less developed ecosystems, heterogeneity in water, carbon, nutrient, and energy cycling may be enhanced, specifically over the short distances associated with urban development patterns. We review conceptual approaches to characterizing and representing heterogeneity in urban ecosystems and illustrate some of the main sources of heterogeneity resulting from interactions within and between urban patch networks, with special reference to examples drawn from the Baltimore Ecosystem Study.

Introduction

Cities are rapidly expanding in both area and population on a global scale. For example, about 80% of the U.S. population currently lives in urban areas as defined by the U.S. Bureau of the Census. In addition, increases in the area of urban land use have typically exceeded increases in urban population, resulting in urban sprawl characterized by lower density and more extensive areas (Berry 1990). The shift in extent and density of cities has resulted in a change in the morphology of urban areas. The formerly compact and uniformly developed coverage of North American cities has evolved into more extensive and spatially heterogeneous patterns that contain significantly contrasting land covers (Garreau 1991). The contemporary metropolis contains lower density urban development including an assemblage of residential, commercial, and industrial land uses interspersed with residual agricultural and forest land, and other unmanaged vegetation (Zipperer et al. 1997). The

current patch network may still maintain some memory of previous states because of slowly changing variables such as soil and groundwater conditions (Effland and Pouyat 1997; Pouyat et al. submitted). Spatial and temporal interactions between different patch types within these areas may be important regulators of aggregate system behavior (Cadenasso et al. 2003b). Distinct dynamics of individual patches can be dependent on local neighborhood connectivity, as well as successional history (Pickett et al. 2004).

This paper discusses the influence of heterogeneity on ecosystem processes in urban environments. We first present and then attempt to integrate a set of conceptual frameworks for representing heterogeneity and its effects in urban ecosystems. The frameworks we seek to integrate include (1) ecological patch dynamics, (2) distributed hydroecological modeling, and (3) urban land-atmosphere interactions.

Our main focuses are on (1) the forms of spatial heterogeneity in urban patch networks, (2) the interaction of human individual and institutional activity with landscape cycling of matter and energy, and (3) the impact and influence of heterogeneity on ecosystem behavior. Throughout the chapter, we maintain an approach that treats urban ecosystems as specific cases of ecosystems in general (Pickett and Cadenasso 2002), varying only in the degree of influence of specific ecosystem "agents," including human activity and the built environment. Illustrative material is drawn from work in several sites but focuses on examples from the Baltimore Ecosystem Study (BES) Long-Term Ecological Research program (http://beslter.org).

Characterization of Urban Ecosystem Heterogeneity

Any ecosystem can be defined in terms of a set of state, flux, and transformation variables that are linked by a set of statements assuming conservation of mass and energy. Animal and plant populations are incorporated through trophic structures that both contribute and respond to the mass and energy regulation of the system. One approach to characterizing the spatial patterns and distributions of the ecosystem is to use patch networks, in which discrete areas, or patches, are interconnected with defined flows of material, energy or information (Kolasa and Pickett 1991; Wu and Loucks 1995). Ecological patch dynamics (Pickett and White 1985; Fahrig 1992; Fisher 1993; Wiens 1995) is a widely recognized approach in the study of landscape ecological patterns that incorporates interactions between patches but also considers the space-time dynamics of patch structures across scales by a set of slow (e.g., successional) and fast (disturbance) processes. Conservation statements are applied to each patch and to the fluxes between and within connected patches. The form of connections (e.g., downslope, first or higher order neighborhoods, land-atmosphere) is crucial to the behavior and properties of each patch and of the full ecosystem and provides crucial linkages between the three frameworks of patch dynamics,