Ecological Signatures: The Science of Sustainable Urban Forms

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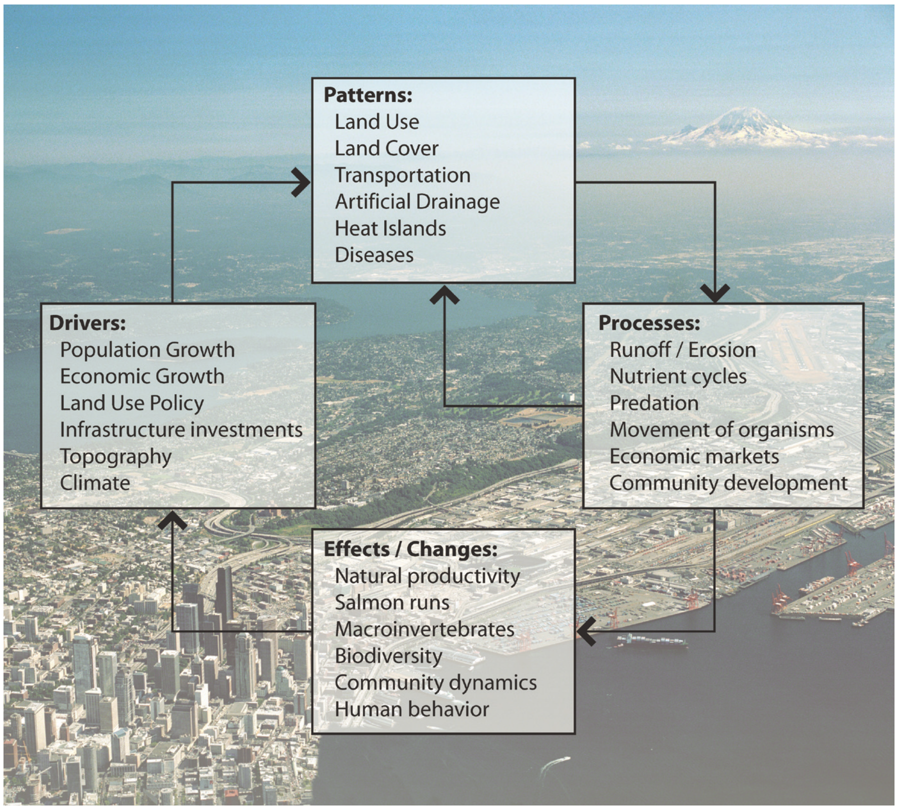


Above: Urban Ecological Model. From Alberti et al., "Integrating Humans into Ecosystems." Background photo © Aerolistphoto.com.

Urban development across the United States dramatically transforms the natural landscape and its ecological function. It fragments and impairs habitat, simplifies and homogenizes species composition, alters hydrological systems, and modifies energy flows and nutrient cycling. In turn, these changes affect the ability of ecosystems to support human functions, the quality of urban environments, and ultimately human well-being.

While is known that different patterns of urban development have predictably different impacts on ecosystem functioning, the exact effects of different forms, densities, and levels of urban connectivity are not well known; nor is the way these interactions vary from place to place. For example, compact development patterns are typically associated with lower impacts on the natural surroundings. But the complex interactions between the patterns of built and natural landscapes in urbanizing regions are actually not well understood. Despite much debate on the ecological impact of alternative urban forms, the proposed relationships between urban patterns and ecosystem functions are still only hypotheses.

In an effort to provide designers and planners with insight on the functioning of coupled human and natural systems, a new research collaboration between the Urban Ecology Research Laboratory (UERL) at the University of Washington and the Global Institute of Sustainability at Arizona State University is developing the concept of ecological signatures.[1] The effort is aimed at quantifying and comparing the actual ecological effects of different development patterns using established scientific tools. This knowledge is essential if future design and planning will be able to lower the impact of new development on a regional scale.

Our contention is that the complex interactions between *human* and *biophysical* processes at a variety of scales give rise to distinctive *landscape patterns*. We call these "ecological signatures." We further propose that the challenge for urban designers and planners in coming decades will be to understand how these patterns emerge, evolve and affect ecosystem dynamics in a much more accurate and fine-grained way.

Detecting Landscape Signatures

In the past, studies of urban environmental impact have focused on the aggregated effect of residential and employment densities on energy consumption and emissions. A prominent view within this literature has been that compact urban form is more ecologically sustainable than dispersed form.[2] Proponents claim that compact form is less energy- and pollution-intensive because it reduces land consumption, preserves open space, and reduces dependence on the automobile.[3]

The empirical evidence for these relationships is, however, limited and controversial, mostly because of methodological problems and the limited generalizability of findings.[4] More robust approaches are emerging on the relationship between urban form and transport efficiency.[5] But the relationships between urban patterns and ecosystem function are still virtually unknown. Furthermore, current study of the interactions between urban patterns and ecosystem processes lacks the conceptual framework to systematically investigate these relationships. Before the effects of urban patterns on ecological resilience can be determined, testable hypotheses must be articulated about the mechanisms linking urban patterns to ecological processes, and significant factors governing these interactions at various scales must be identified.[6]

In urbanizing regions, human actions create both direct and subtle changes in biophysical and ecological processes. For example, urbanization may affect primary productivity, nutrient cycling, hydrological function, and ecosystem dynamics by causing changes in microclimate, hydrology, geomorphology, biogeochemical processes, and biotic interactions.[7]

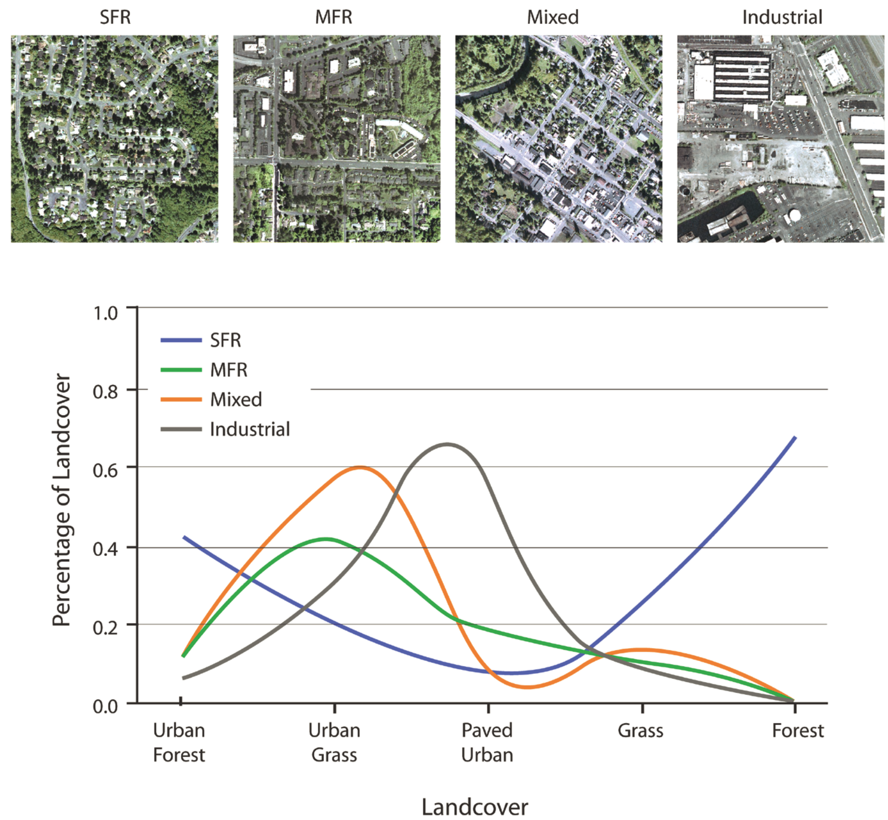
Emerging studies in Baltimore, Phoenix and Seattle are now showing that such complex interactions generate unique landscape patterns.[8] Despite the variability of local biophysical settings and socioeconomic activities within cities, the coupling of human and natural processes may be creating an identifiable biogeochemistry. For example, it has been shown that during the summer Baltimore's mean maximum temperature is higher than in surrounding rural areas.[9] In contrast, the city of Phoenix is cooler than the surrounding desert. In Baltimore, annual nutrient and carbon cycling increases during the longer growing season, while warming in arid Phoenix can suppress photosynthesis during the summer.[10]

Urbanization has been shown to affect biogeochemistry through the clearing of vegetation and the increase in impervious land surface. Urban infrastructure, particularly wastewater and artificial drainage systems, has also been identified as a significant mechanism of change through its effect on waterborne nutrients. Research, however, also reveals that there is no single measure to evaluate the impact of urban form on ecological function. Likewise, we cannot evaluate the aggregated impact of urban form if we do not understand, at a much finer scale, the interactions between development and ecological processes.

As a result, despite much debate and controversy, we still do not know what development pattern is most effective in supporting ecological function. Unfortunately, scientific literature over the last twenty years has not provided the right answers, partly because we have not asked the right questions or used the right methods.

Linking Development Patterns to Ecosystem Function

Emerging approaches in landscape ecology provide a framework for the explicit quantification of the relationships between forms of urbanization and ecological function. At the UERL we are applying these methods to the detection of *distinct ecological signatures* of urban development.[11] Our goal is to provide designers and planners with systematic ways to assess the ecological implications of alternative development patterns and design and to help them plan more sustainable urban landscapes.



Above: Landscape Signatures of Development Types. From Alberti, "The Effects of Urban Patterns on Ecosystem Function," modified. Photos courtesy of Emerge 2002.

These efforts are largely based on the development of new tools to understand the effects of development patterns on biophysical processes and ecological conditions. This work has involved characterizing landscapes in the Seattle metropolitan area according to objective measures of composition and configuration. It has then used these measures to study emerging relationships between landscape patterns and ecosystem dynamics. And using advanced GIS and remote sensing techniques, we have combined longitudinal socioeconomic and ecological data sets to extract signatures of development patterns and simulate future scenarios.

As technology advances the range and availability of data, researchers in landscape ecology have developed a number of metrics for quantifying landscape patterns and their effects on ecological processes.[12] These metrics can also be useful to measure the impacts of urbanization. For example, we have applied measures of percent land cover, mean patch size, contagion, and Shannon diversity index to quantify urban landscape patterns in the Seattle metropolitan area. Percent of land cover occupied by patch type (i.e., paved land, forest, or grass) is an important indicator of ecological function. Mean patch size of forest cover is a measure of fragmentation and an important indicator of natural habitat. Contagion measures the degree of aggregation of a particular form of land cover by measuring the probability that two randomly chosen adjacent cells belong to the same class. The Shannon diversity index represents the number of land use classes in the landscape. We also quantify landscape configuration using indices of aggregation (AI) and percent like adjacency (PLADJ).[13]

To better relate patterns of urban development to ecological processes, we have also developed a typology based on real estate types and land development characteristics, which includes predominant land use, number of units, parcel size, and road infrastructure. We have intersected a 150m vector grid with several GIS layers representing each land use and land-cover dimension to quantify and relate land development types to land cover and built structure characteristics.

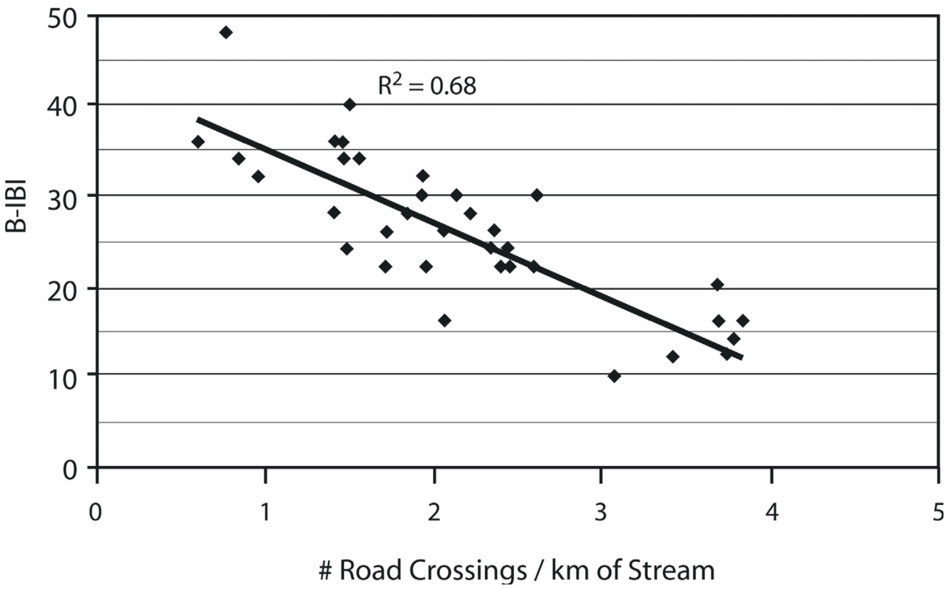
Using these metrics we have developed and tested formal hypotheses of the effect of urban development patterns on such biophysical indicators as bird communities and aquatic macro-invertebrates. We have also attempted to determine what factors determine and maintain an urban ecological gradient.[14]

These initial studies indicate that complex relationships exist between land use, land cover, and ecosystem processes. However, different land uses can be discerned based on the character of their land cover. For example, when studied on a parcel scale, single-family residential landscapes have less impervious surface than multifamily parcels (although multifamily development parcels may accommodate a greater number of households, thus reducing the requirement for impervious surface at a larger scale). The percentage of impervious surface is greater on both mixed-use (residential and commercial) and on industrial parcels. And, in general, more forest cover is found on single-family residential parcels.

Although such trends may be generally predictable, there is great individual variability depending on parcel size, the location of a parcel along an urban-to-rural gradient, and the year a parcel was developed. Our results do, however, show that the amount of natural land cover that can be preserved is determined by land-development type, and that the level of fragmentation that will be generated will be determined by land use.

We have also studied the effect of urban patterns on biotic integrity of streams. These patterns cause changes in runoff and a replacement of riparian vegetation.[15] At the drainage-basin scale, previous research has shown that impervious surfaces result in altered and often extreme hydrologic conditions.[16] However, using the Benthic Index of Biological Integrity (B-IBI) developed by James Karr, we found that the percentages of impervious area and forest in a contributing watershed are only a coarse predictor of biological conditions.[17] Not only the total amount of impervious area but also its spatial configuration were found to affect stream health. The best individual predictors of BIBI we could determine were the number of road crossings and overall road density. Indeed, the location and spatial configuration of forest patches and paved areas explained most of the variability in BIBI.

We have also studied how bird populations respond to urban development. This work explored how regulating mechanisms such as nest predators, vegetation, competing species, and food resources respond to human settlement.[18] We found that bird richness remained high in the settled Seattle region if the percentage of forest in each 100-hectare unit remained at approximately 20 percent or more. But this was not a linear relationship. Bird richness peaked at approximately 50 percent forested landscape. Furthermore, since bird species richness is determined by the balance between retention of native forest birds and the gain of synanthropic species (those that benefit from people) and early successional



species (those that use grasslands and other open forest), bird communities at the urban fringe were found to have high species diversity.[19]

Urban Landscape Patterns as Emergent Phenomena

Such work leaves many questions unanswered. Although many scholars are starting to study the effects of urban development on ecosystems, we do not yet know how urban landscape patterns emerge from complex interactions between human and ecological processes. Furthermore, we do not know how patterns of clustered versus dispersed development control the distribution of energy, materials and organisms in urbanizing landscapes.

This is why participants in the new research project at the University of Washington and Arizona State University have begun to investigate the complex coupled human/natural system dynamics of the Seattle and Phoenix metropolitan areas.[20] The study aims to empirically test hypotheses about how the interactions of human agents (i.e., households), real estate markets (i.e., housing prices), built infrastructure (i.e., roads and wastewater), and biophysical factors (i.e., topography and land cover) drive current patterns of development, and how these patterns affect human and ecological function in two very different bioregions.

In urban areas, the study imagines that changes in land cover may have a complex interactive influence on biophysical processes and biodiversity. In particular, change in land cover may feed back on choices of household location and affect land value and real estate markets.

The study addresses four questions: 1) How do dynamic landscape systems help generate the patterns that we see in emerging urban landscapes? 2) What nonlinearities, thresholds, discontinuities, and path dependencies explain divergent trajectories of urban landscapes? 3) How do emergent urban landscape patterns influence biodiversity and ecosystem function? and 4) How can planning integrate this knowledge to develop sustainable urban landscape patterns?

Designing Sustainable Urban Landscape Patterns

The interdependence of human and natural processes places unprecedented challenges to integrate ecology in urban design and planning. Strategies for managing urban growth and guiding urban form require a new understanding of the complex interactions between human and ecological processes to prevent and minimize unnecessary impacts. Ecological resilience in urban ecosystems depends on simultaneous maintenance of natural and human functions over the long term.

Because different urban development patterns imply diverse amounts and levels of interspersion of built and natural land cover and because they present varying demands on natural resources, we know that alternative patterns of urban development will have different ecological signatures. But the ability to specify which degree of compactness, density, connectivity and heterogeneity of the urban fabric, at scales from building to region, best sustain ecological function should be based on much more research. Furthermore, decisions about alternative strategies for urban design, land use planning, transportation and wastewater infrastructure require an understanding of the mechanisms that link urban patterns to both human and ecosystem functions.

Empirical evidence indicates that patterns of urban development do matter in balancing human and ecological function. But it also indicates that ecosystem responses vary according to ecological processes and place. These relationships are sometimes nonlinear,

Above: Number of roads crossing a stream vs. stream biotic integrity in Puget Sound lowland. From Alberti et al., “The Impact of Urban Patterns on Aquatic Ecosystems.”

with sharp thresholds where ecological conditions may change abruptly.

Despite the rush to create explicit design and planning guidelines, current research has found no one form of development that fits all ecological processes and best helps protect biodiversity. The optimal landscape form depends on specific conditions. Moreover, maintaining a diversity of landscapes and thus promoting diverse development patterns may be crucial to ecological resilience and to support a diversity of species and ecosystem functions.

The lesson to be learned is that the environment is much more variable and complex than has yet been conceptualized. Change in environmental systems is also inevitable. Furthermore, in real systems there are multiple equilibria, and the best response may change under varying and evolving conditions. Such an understanding is critical to creating sustainable urban landscapes.

Notes

1. M. Alberti with C. Redman, J. Wu, J. Marzluff, M. Handcock, J.M. Anderies, P. Waddell, D. Fox, H. Kautz, L. Hutyra, S. Walters, and J. Hepinstall, "Urban Landscape Patterns: Complex Dynamics and Emergent Properties." This collaboration is funded by the National Science Foundation as part of the Biocomplexity Program BE/CNH (BCS 0508002). The project is a joint effort by the UW Urban Ecology Research Lab (www.urbaneco.washington.edu) and the ASU Global Institute of Sustainability (http://sustainable.asu.edu/gios).

2. R.Y. Jabareen, "Sustainable Urban Forms: Their Typologies, Models, and Concepts," *Journal of Planning Education and Research*, Vol. 26, No. 9 (2006), pp. 38-52.

3. See, for example, Peter Calthorpe, *The Next American Metropolis: Ecology, Community, and the American Dream* (New York: Princeton Architectural Press, 1993); and Andrés M. Duany and Elizabeth Plater-Zyberk, "The Second Coming of the American Small Town," *Wilson Quarterly*, 16 (1992), pp. 19-51.

4. Randall Crane and Richard Crepeau, "Does Neighborhood Design Influence Travel? A Behavioral Analysis of Travel Diary and GIS Data," Institute of Transportation Studies, Center for Activity Systems Analysis, University of California, Irvine, 1998.

5. See, for example, A. Moudon and D.W. Sohn, "Transportation-Efficient Land Use Mapping (TELUMI): Phase 3 of Integrating Land Use and Transportation Investment Decision-Making," Washington State Transportation Research Center, WA-RD 620.1, 2005. Full report at http://depts.washington.edu/trac/bulkdisk/pdf/620.1.pdf.

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9. J.P. Kaye, P.M. Groffman, N.B. Grimm, L.A. Baker, and R.V. Pouyat, "A Distinct Urban Biogeochemistry?" *Trends in Ecology & Evolution*, 21 (2006), pp. 192-99.

10. Ibid.

11. The UERL Team involved in the study of ecological signatures of urban development involves several research associates and assistants, including L. Hutyra, S. Walters, S. Coe, D. Spirandelli, Y. Jang, M. Russo, and K. Puruncajas. See Alberti et al., "Integrating Humans into Ecosystems."

12. M.G. Turner, R. Costanza, and F.H. Sklar, "Methods to Evaluate the Performance of Spatial Simulation Models," *Ecological Modelling*, 48 (1989), pp. 1-18.

13. Land use data at the parcel level were obtained from the King and Snohomish County assessor offices. Land cover data were interpreted from Landsat Thematic Mapper (TM) imagery for the Puget Sound region for 1998. Landscape metrics were measured with Fragstats 3.1. K. McGarigal, S.A. Cushman, M.C. Neel, and E. Ene, Spatial Pattern Analysis Program for Categorical Maps, 2002., www.umass.edu/landeco/research/fragstats/fragstats.html.

14. Alberti and Marzluff, "Ecological Resilience in Urban Ecosystems,"; and M. Alberti, D. Booth, K. Hill, C. Avolio, B. Coburn, S. Coe, and D. Spirandelli, "The Impact of Urban Patterns on Aquatic Ecosystems: An Empirical Analysis in Puget Lowland Sub-Basins," *Landscape and Urban Planning*, Vol. 80, No. 4 (2007).

15. Alberti et al., "The Impact of Urban Patterns on Aquatic Ecosystems."

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