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Importance of Integrated Approaches and Perspectives

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Abstract

Ecology has traditionally neglected the role of people as components of ecosystems, and in particular has been largely absent from urban and other densely settled and built ecosystems. However, ecologists have finally come to realize that people and their effects are part of both seemingly wild and clearly urban ecosystems. This recognition has called for increased integration between the social sciences and biophysical sciences. This novel integration has exploited the increasingly important interfaces between urban and rural or wild systems. The frameworks of (i) patch dynamics, (ii) the watershed, and (iii) the human ecosystem concept have supported integrated research, education, and community engagement. The chapter uses the Baltimore Ecosystem Study, Long-Term Ecological Research program to exemplify how these frameworks are used to formulate and answer questions shared by social and biophysical sciences. Furthermore, shared research and restoration sites, and a shared concern with neighborhood quality of life, environmental quality, and ultimately with urban sustainability continue to promote integration across disciplines and embed socio-ecological research and education in the decision making and community life of Baltimore.

Linking People with Nature: The Surprise of People in the Wild and the Urban Extreme

In the past, most ecologists focused their research on places where people were absent, rare, or at least inconspicuous. This focus generated a powerful body of knowledge that permits understanding of forests, deserts, grasslands, and fields in terrestrial environments, and an equally broad understanding of estuaries, lakes, streams, wetlands, and bogs among aquatic habitats. The reasons for this bias against sites in which people play a predominant role are many. There is the legitimate desire to understand how evolution and ecological interactions, on their own, have generated resilient systems (Thompson, 1982). There is the desire to know how self-organizing communities and ecosystems come to be and how they change through time (Walker, 1999). There are also more personal concerns—the pleasure in working in inspiring landscapes or places where a wilderness challenge must be overcome to investigate them successfully. There is perhaps also a fear that people represent a case of messy and capricious causality, one that will not expose law-like regularities. Whatever the reasons, the biases and pleasures of the majority of

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ecologists have generated a tradition that has left a gap in knowledge about urban systems and their reciprocal interactions with other kinds of ecological places (Grimm et al., 2000; McDonnell and Hahs, 2009). Or worse, the biases often left ecologists blind to the role that people actually played in many ecosystems.

In the second half of the 20th century, more and more ecologists came to appreciate that a full understanding of the systems they studied required knowing what people are doing, and had done, in many landscapes (Gomez-Pompa and Kaus, 1992; McDonnell and Pickett, 1993; Russell, 1997). Successional trajectories in fact included the effects of prior land management. The susceptibility of forests to disturbance reflected past manipulations of the plant communities by indigenous peoples. Soils and species composition in some tropical habitats were the result of extensive soil amendment and husbandry of useful plants. Now ecologists have recognized hybrid social–natural biomes, or "anthromes" and have documented their broad coverage of the Earth's surface (Ellis et al., 2010). Furthermore, as people's technologies or cultures changed, so did the ecosystems they managed. As carnivores were extirpated by hunting, which in turn gave way to passive recreation, expansions of herbivores changed the composition of forests and grasslands. Such an accumulating weight of evidence for the role of humans in ecosystems led ecology from being a science primarily of the wild and lightly inhabited to a science interested in addressing fully urban situations (McDonnell, 2011).

One path of this transition in North America led through the urban–rural interface (McDonnell and Pickett, 1990). In part this transition is the result of the expanding contact zone between urban and nonurban, wild, or managed landscapes. Urban areas, defined here to include suburbs, and exurban settlements that draw on urban capital, lifestyle, and economic resources (Rybczynski, 2010), are rapidly growing in size throughout the world (United Nations Population Fund, 2007). Already, for example, the area of impervious surface in the United States equals the size of the state of Ohio (Elvidge et al., 2004). Such a vast and fragmented territory represents a new mingling of human structures and processes with bioecological patterns and functions. Because all ecosystems, no matter how seemingly pristine, bear the past or ongoing stamp of human actions (Vitousek et al., 1997), understanding the interaction of human and bioecological processes and structures throughout the gradient from wild to core city is a pressing need for the science and application of ecology.

This chapter examines the integrated approach that has been used by a group of natural and social scientists in studying the Baltimore, MD metropolitan area as a socioecological system. The research program, funded by the National Science Foundation, with in-kind support from the USDA Forest Service, and support from additional granting agencies, is known as the Baltimore Ecosystem Study (BES), Long-Term Ecological Research (LTER) program (www.beslter.org). In this chapter we outline the tools used for cross-disciplinary linkage in this project. These include shared frameworks, shared research questions, shared study sites, and engagement with the concerns of communities and policymakers. The chapter includes empirical examples of unexpected or functionally significant findings that have resulted from attempts to accomplish integrated research in Baltimore and a discussion of challenges remaining in the integration of understanding in human ecosystems.

Shared Frameworks

The Baltimore Ecosystem Study is beginning its third funding cycle and has been in operation since 1997. It has used three conceptual frameworks. These are not the only possible frameworks for urban socioecological research, but they have characteristics that are likely to be useful beyond Baltimore. The main conceptual framing devices are: (i) patch dynamics, (ii) the watershed concept, and (iii) the human ecosystem framework. The first two frameworks emerged in the biophysical sciences, but when complemented by the human ecosystem framework, become useful in urban areas. Urbanists, including planners, architects, and landscape architects, consider urban areas to be complex mosaics and networks that have many centers of activity spread widely across regional and even continental scales (Gillham, 2002; Oswald and Baccini, 2003; United Nations, 2007). The frameworks are useful for addressing the coupling of human and natural processes and structures across the spatially heterogeneous mosaics constituting urban areas.

All three frameworks are characterized by the attempt to be comprehensive in their causal scope, to provide nested hierarchical structure that ranges from general to specific mechanisms and processes, and to be adaptable in the face of new findings and approaches.

Patch Dynamics

This framework has a long history in ecology (Pickett and White, 1985; Kolasa and Pickett, 1991; Hutchings et al., 2000). It is relevant to urban areas because of the great spatial heterogeneity and dynamism in urban areas (McGrath et al., 2007). Neighborhoods and districts often change abruptly in urban areas, with sharp boundaries based on both social and biophysical features and processes. For example, patches can be delimited based on architecture, vegetation, and kind and level of human activity. Patches may even exist within a coarse land use class, such as residential. For example, a patch inhabited by young families with children contrasts with quieter enclaves predominantly housing older, retired persons or couples whose children have grown and moved away. Patches whose residential streets are overarched by mature trees contrast with those where sidewalks are exposed to the full glare of the summer sun. Consequently, patches within cities and suburbs can exhibit greater or lesser heat island effects, depending on their vegetated and built structure. Similarly, a patch may be defined by the repair of faulty sewers in contrast to patches that retain older infrastructure at risk of contaminating streams. Patches also exist in urban soils, although they may be inconspicuous to many people (Pouyat et al., 2010). Such patchiness may reflect the native soil formation processes of the region, the burial of soil profiles by fill and construction, and the reshaping of topography to accommodate buildings and transportation based on land and water.

Such spatial heterogeneity is not permanent. Although architecture and street patterns may have relatively long life spans in urban areas, patches can change as vegetation matures and trees senesce, as families age, as institutions lose or gain social vitality, or as economic investment shifts from older to newer commercial districts. Indeed, even buildings can become obsolete and be replaced, expanded, or modified. Such actions affect the amount of open space, the potential for planting ornamental or productive vegetation. Changes in spatial heterogeneity can also result from social factors. Heterogeneous social conditions are exemplified by the attitudes and expectations of agencies and citizens. These may shift in time as well as space. For example the growing interest in urban agriculture inserts new land covers and uses in parts of older urban areas.

The dynamics of individual patches thus reflect a variety of social and biophysical causes (Fig. 14–1). Such a rich array of possible changes lends great complexity and diversity to the structure and function of urban areas. Both social and natural scientists can use patch dynamics as a framework for their research and for comparisons and joint modeling of change.

Fig. 14–1. The array of HERCULES patches in the Gwynns Falls Watershed of Baltimore City and Baltimore County, MD.

The Watershed

Hydrological catchments and basins are another powerful integrative tool. This is due to the fact that as water flows from drainage divides through headwaters and into larger drainage channels, it integrates the physical, chemical, and biological characteristics it encounters. This feature has been widely and effectively used in ecological studies outside of urban areas. Effects of clearcutting, acid rain, and forest succession are among the phenomena that are better understood as a result of watershed based research (Likens and Bormann, 1995). Stream chemistry, stream flow, and sediment load all can reflect the physical structures of slope, substrate and surface chemistry, biological activities, and contamination present within the watershed. Because social actions and human artifacts are also parts of watersheds, we assumed that the integrative power of watersheds would serve the human ecosystem as it had biogeophysical research.

The spatial heterogeneity within watersheds determines the pathways through which water flows both above and below ground. Hence, the heterogeneity recognized in patch dynamics complements the watershed approach. Flow paths of water traverse different combinations of patches, and one of the goals of urban watershed research is to elucidate the influence of heterogeneity on water quality and quantity in, and downstream of, urban watersheds. Toward this end, a more refined classification scheme to describe urban heterogeneity has been developed (Ellis et al., 2006; Cadenasso et al., 2007b). This method has confirmed the role of fine- and medium-scale heterogeneity on ecological functions in urban areas.

The Human Ecosystem

Implied in both the patch dynamics and the watershed frameworks is the intimate involvement of humans, both as individual and as aggregate actors, and as generators of some of the heterogeneity those frameworks reflect. The human ecosystem framework is a tool to elucidate the components and pathways of that involvement. It considers people to be an inextricable part of the urban system. Even the concept of coupled human–natural systems does not do justice to the intimacy of the hybridization of human and biophysical phenomena in urban systems. It is the human ecosystem framework that identifies the immense causal richness of human agency and response in urban ecosystems (Fig. 14–2). The components of the human ecosystem framework are the raw material for specific hypotheses about structure and function in urban systems. Specific models will use some subset of the causes to generate hypotheses about how an urban area or situation operates or changes through time.

To generate process models from the human ecosystem framework, it is necessary to exploit the functional linkages that can exist in any ecosystem. The fundamental definition of an ecosystem is a bounded volume of the Earth in which biotic and physical complexes interact with each other (Likens, 1992). The concept emphasizes that the organisms and their products, and the physical resources, constraints, and enablers are inseparable parts of a single system. However, in addressing urban areas and urban–rural interfaces, it is also important to recognize that the buildings, infrastructure, and resources that people bring to cities, and the wastes and transformed materials generated there are also part of the urban ecosystem. Indeed, so are the social structures that people generate to manage themselves, the resources they require, and the expressions of culture (Fig. 14–2). Institutions of various scales, degrees of permanence, and formality are all part of the human ecosystem of urban areas (Pickett and Grove, 2009).

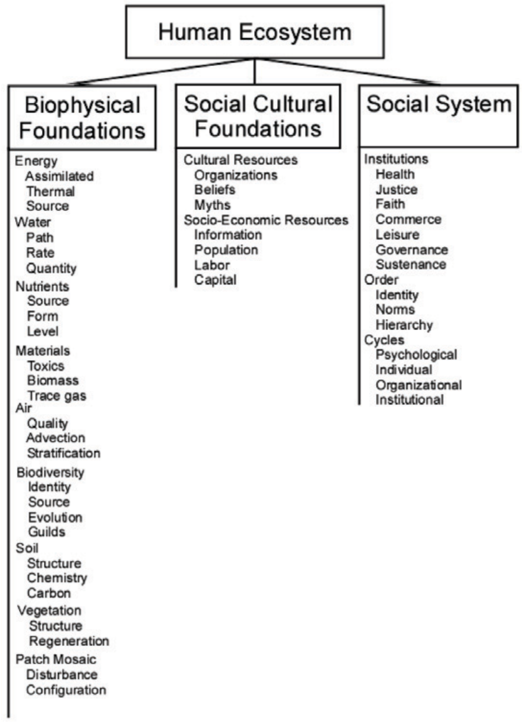

Fig. 14–2. The Human Ecosystem Framework as employed by the Baltimore Ecosystem Study, Long-Term Ecological Research.

Shared Questions

The research questions motivating the Baltimore Ecosystem Study have served as integrating tools (Cadenasso et al., 2006). These questions were chosen because they are fundamental to any kind of scientific understanding, from biophysical and social realms. Furthermore, because of their generality, they are easy for a diverse community of researchers and educators, spread widely over the United States, to recall and use in their interactions.

The most general and hence fundamental questions are these:

Question 1. How does the spatial structure of ecological, physical, and socioeconomic factors in the metropolis affect ecosystem function? This question focuses on spatial heterogeneity and encourages joint examination of both social and biophysical heterogeneity. Implied in this question is the concern with long-term change in heterogeneity.

Question 2. What are the fluxes of energy and matter in urban ecosystems, and how do those fluxes change over the long term? This question focuses on two key processes—matter and energy flow—that link the components of any ecosystem. Matter and energy are likewise key to the functioning of urban ecosystems, as illustrated by the acquisition of construction materials, food, fuel, water, and industrial raw materials, as well as the displacement or recycling of wastes, or materials judged to be hazardous or in excesses. Cities are conspicuous generators of heat, water runoff, sewage, solid waste, and the like (Melosi, 2000). At the same time, they are also loci of efficiencies in resource use, such as energy, and are great sources of creativity and innovation (Rybczynski, 2010; Glaeser, 2011). This guiding question implies a concern with the linkage between spatial heterogeneity and the biophysical and social functioning of urban ecosystems.

Question 3. How can urban residents develop and use an understanding of the metropolis as an ecological system to improve the quality of their environment and their daily lives? This third question focuses on the generation and flux of information. In particular it recognizes that the presence of a socioecological research and education program in an urban area may well affect the behavior of the system or its parts. This question promotes examination of the self awareness of the urban system and its capacity for environmental learning. It also highlights the need to incorporate humans as a fundamental component of ecosystems, rather than as an external forcing factor.

Within and between each of the topic areas defined by one of the three fundamental questions there are more specific research questions. Although many of these questions address traditional disciplinary concerns, many others are squarely at the interface between the social and biophysical realms. For example, a question about biophysical structure asks about the distribution and change of tree cover across the metropolis in this originally forested region. An integrative question asks, what is the relationship between vegetation structure and composition and the social characteristics of the patch in which the vegetation occurs (Troy et al., 2007)? A more refined integrative question asks, how are social and biophysical determinants of biodiversity related in different neighborhoods? A further example of a specific research question comes from hydrology and posits that flow patterns in Baltimore streams will reflect the expected urban "flashy" pattern with high levels of nutrient loading. An integrative question examines how lawn management may contribute to the patterns of nutrient loading by neighborhood (Raciti et al., 2011). In the social realm, a finer scale question is motivated by the desire to understand to what extent traditional social variables such as race, income, and education explain differences in biophysical processes in neighborhoods compared to the market segmentation characteristics of a consumption-based economy (Grove et al., 2006). For Question 3 above, concerning information feedback, a representative question asks, what are the ecological assumptions that students bring to after school programs in environmental literacy?

An important aspect of our guiding questions is their capacity to evolve. As we move from the second to the third 6-year funding cycle for BES, a new overarching question has been identified. This question recognizes the changing policy environment as the main jurisdictions in the Baltimore region begin to focus on sustainability as a major concern. Furthermore, as citizens and governments begin to ask questions about climate change and planning for such change, concern with future scenarios rises in importance as a research topic. Therefore, the new guiding question for BES in the third funding cycle is the following: How do biogeophysical and social adaptive processes influence and respond to policies aimed at enhancing sustainability in the Baltimore region?

Focusing on adaptive processes and, more specifically, their measurable determinants (Fig. 14–3), means that our research findings should be more useful in the realm of sustainability planning and assessment (Pickett et al., 2011). Adaptive processes are the kinds of capital and phenomena, existing in both the social and the biophysical components of the urban ecosystem, that allow or constrain its ability to respond to changing conditions. While many of the adaptive processes are topics of interest to basic science, their relevance to resilience and sustainability adds an important dimension to the research (Gunderson et al., 2002; Yohe and Tol, 2002).

Shared Sites and Shared Tools

The sites for research and education have served as venues for integration across disciplines in BES. For example, the subcatchments of the major watersheds reflect different land covers and land uses. Pond Branch is a forested headwater catchment that serves as a nonurban reference and is tributary to Baisman Run, a watershed occupied by large-lot, suburban housing served by wells and septic systems. Gwynnbrook is a headwater stream supporting a mix of old and new suburban development, an old village, and some marshy open land. The suburban developments in this catchment are served by sanitary sewers and municipal water. The remaining subcatchments of the Gwynns Falls reflect increasing intensities of urbanization, ranging from Dead Run, which contains 1960s era suburbs, contemporary big box stores, and a county park supporting a riparian woodland, through an unnamed drainage in the Rognel Heights neighborhood consisting of a curb and storm drain catchment, to Gwynns Run, a tributary draining industrial, transportation, and old residential areas in the city. Each of these subwatersheds has been the focus of water flow and stream chemistry studies, social science research, urban design projects, and patch analysis (Groffman et al., 2004; Kaushal et al., 2005; Kaushal et al., 2008a; Shields et al., 2008).

An example of an integrative tool that has emerged from different perspectives on the same landscape is the development of the High Ecological Resolution Classification for Urban Landscapes and Environmental Systems (HERCULES) land cover classification (Cadenasso et al., 2007). Traditional land use and land cover classifications in urban areas take a disaggregated approach to the subject matter. Most are derived from the Anderson et al. (1976) approach, in which vegetated and urban covers constitute a high-level separation. Lands are either forest, agricultural, or urban. Within urban lands types, uses are recognized: transportation, commercial, and residential. As a refinement, residential lands are separated into high, medium, and low densities.

Such disaggregated schemes miss much of the structural integration that actually exists in urban systems. All urban areas comprise three basic cover types: surfaces, plant canopies, and buildings (Ridd, 1995). Surfaces may be paved or bare. Plant canopies can be herbaceous or dominated by woody species. Buildings can be of various types. Within a given area, the proportion of each cover type can be assessed. Hence, HERCULES reflects the integrated nature of urban land covers, comprising as they do built components, surface covers, and vegetation.

This purely cover-based system can be combined with other functional or use-based data

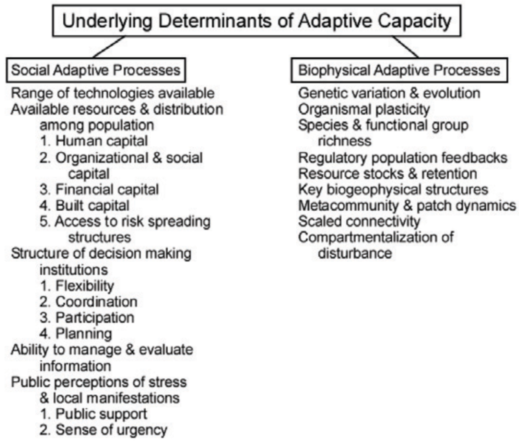

Fig. 14–3. The underlying determinants of adaptive capacity in socioecological systems.

layers to evaluate relationships between different components of urban systems. For example, housing types such as apartments or single family occupancy can be obtained from municipal records, zoning codes, or social surveys. Locations of different social arrangements or groups having contrasting lifestyles and environmental attitudes can be discovered and related to the structural differences exposed by the classification. Hence, a structural classification such as HERCULES itself integrates across built and natural components of a conurbation, and allows specific relationships between social and ecological structures and functions to be quantified and represented.

Policy and Management Motivation

There are three motivations toward relevance for BES research. Funding by the National Science Foundation carries the expectation that research will contribute to fundamental understanding as well as have relevance to larger societal needs. Support by the USDA Forest Service carries with it a requirement to contribute to human well-being and to the store of knowledge about America's forests and rangelands. The third motivation for linking research and education of BES to policy and management needs is a responsibility to the citizens and managers in whose yards, parks, rights of way, and neighborhoods we work.

Fortunately, the responsibility to link with policy and management concerns is matched by abundant opportunities in urban systems. Often management actions, whether performed by agencies or communities, lack the means for scientific evaluation. For example, BES has contributed measurements of stream and riparian function to a restoration project at Minebank Run in Baltimore County (Mayer et al., 2004; Kaushal et al., 2008b; Klocker et al., 2009; Mayer et al., 2010; Harrison et al., 2011). In Baltimore City, BES stream measurements have documented water quality improvements resulting from retrofitting sewers required by court action pursuant to USEPA mandates. In a dense rowhouse neighborhood, a combination of activities—replacement of unneeded asphalt in school yards with grass and trees, installation of curb and alley based best management practices for stormwater, and installation of community gardens and management of vacant lots—has been evaluated in terms of social effects and water quality in buried streams and storm drain infrastructure.

The breadth of opportunities to contribute to policy and management is captured in several sustainability plans that now exist or are being developed in the Baltimore region. The State of Maryland has an Office of Sustainable Futures within its Department of Natural Resources. Baltimore County has recast its Department of Environmental Protection and Resource Management as its Department of Environmental Protection and Sustainability. Baltimore City (Baltimore City, 2009) has developed a seven-point Sustainability Plan, which addresses a broad range of social and environmental concerns (Box 14–1). The city Sustainability Plan is notable for having been generated by a citizen-based Sustainability Commission, originally in the Mayor's Office and now housed in the Department of Planning, which drew on input and dialog involving 1200 diverse residents from throughout Baltimore City. The Baltimore Ecosystem Study, with the Office of Sustainability in the City, is exploring ways to align research and educational activities with the Sustainability Plan. In addition, urban designers in BES are supervising graduate and advanced undergraduate architecture and planning studios at Parsons The New School for Design, which are stimulated by the vision of the sustainability office.

Box 14–1. Components of the Baltimore City Sustainability Plan.

1. Cleanliness
2. Pollution prevention
3. Resource conservation
4. Greening
5. Transportation
6. Green economy

The Plan cites four cross-cutting themes:

- Climate
- Equity
- Public health
- Finance

Lessons from Linkage: Empirical Examples and Experiences

Empirical knowledge and practical application have both been advanced as a result of the linkages across disciplines and between fundamental and problem-oriented concerns discussed above. We give several examples of lessons that have been learned in pursuing the various research and practical linkages.

People and Vegetation

One example of the relationship between people and vegetation is a coarse-scale relationship, while the second provides a more highly socially resolved assessment of vegetation–people relationships. At the coarse scale, across the entire residential cover of the Gywnns Falls watershed in Baltimore, Grove and Burch (1997) discovered a powerful relationship between the amount of canopy cover and pervious surface and two social variables—income and education. Greater amounts of vegetation per census block group were associated with higher incomes and greater educational levels (Fig. 14–4). However, the best relationship was between the 1990 vegetation and the 1970 census. Thus, there was a lag between the potential social drivers and the vegetation. This kind of lag was further evaluated by Boone et al. (2009).

A more spatially refined analysis was conducted by Troy et al. (2007). They found that lifestyle was a better predictor of the potential for increasing vegetation on individual parcels, while the more straightforward demographic variables such as income and education were better predictors of the actual vegetation on residential parcels. Data on investment in yard care products, housing age, vacancy, and population density were additional variables that had predictive power in the multivariate analysis.

Grove et al. (2006) found that variation of vegetation cover in riparian areas was not explained by theories of population density, social status, and lifestyle. However, on private parcels, lifestyle behavior was the best predictor of vegetation cover. Surprisingly, lifestyle behavior was also the best predictor of vegetation cover in public rights of way outside the riparian zones. A statistical model in the form of a quadratic

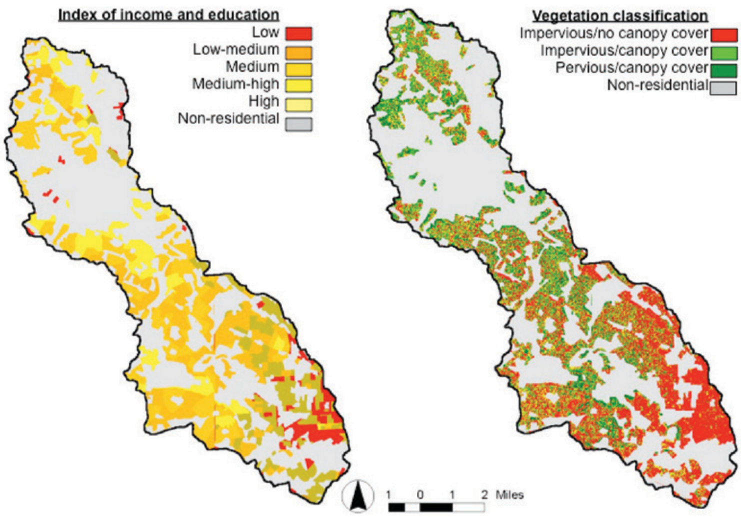

Fig. 14–4. A comparison of income and education in 1970 and vegetation and surface characteristics from 1990 in the Gwynns Falls Watershed of Baltimore, MD.

equation found a significant role for housing age. The management of urban vegetation can be improved by developing environmental marketing strategies that tease out household motivations for and degree of participation in local land management.

Streams and Pollution

Globally, population density is a major determinant of stream pollution. However, within the Baltimore region there is considerable spatial heterogeneity in pollution as exemplified by nitrate levels in streams (Groffman et al., 2004; Kaushal et al., 2005; Kaushal et al., 2008a; Shields et al., 2008). In Baltimore, this pollutant is of concern both as a drinking water contaminant and as a cause of eutrophication in the Chesapeake Bay. The transect and subsampling strategy for stream sampling in BES has exposed unexpected patterns in nitrate contamination. Nitrate concentrations are higher in suburban reaches than deeper in the city (Fig. 14–5). However, organic forms of nitrogen, suggesting sanitary sewer contamination, are higher downstream. As noted above, sanitary sewer retrofits in subcatchments in the city reduced nitrogen contamination.

The capacity of riparian zones to reduce nitrate movement from terrestrial land covers to streams has been demonstrated in extensive research outside of urban areas (Peterjohn and Correll, 1984; Mayer et al., 2007). As a result of this knowledge, it was assumed that riparian restoration in urban areas would have a positive outcome on nitrogen pollution from cities. However, our research in Baltimore riparian zones showed that although on the coarse scale, there was nitrate retention in both residential and embedded agricultural catchments, local riparian zones often did not perform the expected nitrogen removal function (Groffman et al., 2002, 2003; Groffman and Crawford, 2003; Gift et al., 2010). The dysfunction was caused by a complex sequence of events and features, which together

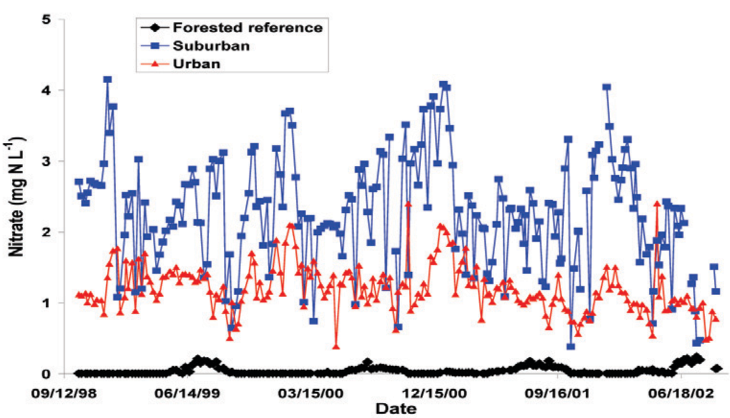

Fig. 14–5. Nitrate concentrations in the forested reference catchment, suburban, and center city catchments in metropolitan Baltimore, MD.

are labeled the urban stream syndrome (Walsh et al., 2005): high surface runoff, a tendency for flash flooding, downcutting of stream beds and stranding of floodplains, reduced water infiltration into urban soil, sinking of the floodplain water table, hydrological drought on floodplains, and aerobic conditions that inhibit the anaerobic denitrification process that converts nitrate in nitrogen gases. Collaborations with managers in the Baltimore region led them to conclude that simply restoring urban riparian zones was inadequate to the task of limiting nitrate pollution in local streams and in the Chesapeake Bay. Therefore, programs were instituted to extend management across entire catchments. In other words, the riparian zone was spatially extended (Cadenasso et al., 2008). Strategies were adopted widely, including pavement removal, tree planting, management of vacant lots to absorb runoff water, and installation of curb cuts and rain gardens to reduce runoff and encourage infiltration. Many of these interventions had the advantage of engaging neighborhoods groups, afterschool programs for youth, and training in green jobs.

Dialog vs. Outreach

The empirical and practical examples above point out an important lesson for linking science and management. The traditional model of scientific interaction with management is one of delivery: from science to use. However, in our experience, the sharing of community, policy, management, and scientific concerns and information was the key to management success in the examples just outlined. Regular communication involving the citizen, agency, and research communities on equal footing to discuss results, new projects, or social issues, allowed shared projects to evolve (Pickett et al., 2007).

The Necessity of Long Times

The Baltimore Ecosystem Study as a long-term program has the luxury of being able to develop and sustain two kinds of relationships necessary for the linkages across disciplines and between research and the communities with which we work. One is the relationship with different disciplines, and the other is the relationship with decision makers.

Interdisciplinary linkages require long times to mature. Often, such relationships are described as developing a shared vocabulary. However, the recognition of words held in common may be only superficial. It takes time to reach a mutual understanding of the assumptions, conceptual structures, and empirical foundations for sharing. In other words, a shared vocabulary is only a relatively early stage in interdisciplinary interaction. It has taken us repeated meetings, informal conversations, and even some pointed misunderstandings of our shared vocabulary, to advance our common understanding. The conceptual frameworks described above have been important tools in this quest, but the repeated opportunities to work with these frameworks across disciplines has been key to our advancing interdisciplinary linkages.

A second benefit of long-term interactions has emerged from the interface between management and research. Developing trusting relationships and learning something of the cultures of each group have been important for smoothing the communication between research and policy and management. Initially, formal connections were facilitated by a monthly committee meeting called the Revitalizing Baltimore Technical Committee, organized by the Parks & People Foundation. Additional venues for interaction have included the quarterly research meetings of BES, at which agency representatives are usually present, and environmentally oriented meetings sponsored by city and county agencies, community and nongovernmental organizations.

An example of an empirical result from agency–researcher interactions is the analysis of salinity in Baltimore streams (Kaushal et al., 2005). Although the city of Baltimore had been collecting such data for decades, the pressures of day-to-day activities had not allowed them to analyze the data. Following interactions with BES researchers that documented high levels of salinity in local streams, city water managers and BES researchers collaborated to expose long-term trends in salt content of streams emptying into the Baltimore City reservoirs. These three reservoirs supply drinking water to residents in both the city and the county.

Challenges

Nurturing a Culture of Collaboration

Integration depends foremost on effective collaboration. This is difficult because of the different professional cultures that participants represent, because of different theories held, because of geographic dispersion of participants, and because of the time commitment required (Pickett et al., 1999). We have acknowledged these challenges and have tried to meet them in adaptive ways.

Building a shared culture in BES has relied on several things. We hold four meetings per year in

Baltimore to which all participants in the project and interested decisionmakers and other community members are invited. These meetings are publically announced on the project web page under "What's New?" The roster of participants in these quarterly meetings typically includes senior academic and agency natural- and social-science researchers, post-doctoral associates, graduate students, undergraduate students, education researchers and program leaders, teachers, governmental managers and policymakers, partners from nongovernmental organizations, and environmental activists. Disciplines represented include urban design, social-economic sciences, biology, physical sciences, and education. One of the four meetings is highlighted as the Annual Meeting, which includes talks and posters summarizing recent results or presenting plans for future research and community engagement. A keynote address emphasizes some opportunity for cross disciplinary interaction, theoretical unification, or practical utility, and the Project Director usually speaks about the mechanics or philosophy that can promote integration in BES. Abstracts of talks at the Annual Meeting are published online (www.beslter.org).

The other three meetings have as their topics educational and research planning and discussions that are intended to build bridges between laboratories and disciplines. Associated with the summer meeting is a graduate student symposium, organized by the graduate students themselves, and providing an opportunity to present plans and results, share perspectives, and discuss common issues as graduate student members of a spatially dispersed project. Research proposals, action plans, and research designs are often products of these quarterly meetings. Research papers have occasionally been the outcome as well.

One characteristic of the meetings is that they are in accordance with a series of rules that were established by the BES community at its first project-wide meeting after the grant was funded. Stimulated by the late M. Gordon "Reds" Wolman, these rules ensure that all voices are heard (Box 14–2).

Box 14–2. The Baltimore Rules for Project Meetings

1. Identify the leader for the session.
2. There will be only one conversation at a time in the session. If replicate or separate conversations are needed, break out groups should be established.
3. Raise your hand to be recognized by the leader.
4. Do not monopolize the floor once you have been recognized.
5. Not all silence is bad.
6. Expect occasional "2-minute drills."
7. If you need to take a break, feel free to do so.
8. The leader can change the rules.

Note: A "2-minute drill" is a tool to punctuate the discussion with occasional stock-taking. Each member of the group is asked for a short reaction or comment on the substance of the discussion. Brief means a sentence or two, not necessarily as long as 2 minutes, if the group is large. A 2-minute drill also ensures that all persons have a chance to speak. A member may "pass" without prejudice, but no member gets two turns.

Metaphor and Substance

Particularly important in building an integrative culture and frameworks for research is the use of metaphor, and how metaphor contrasts with substance. Metaphor is often the provocative introduction to dialog (Pickett and Cadenasso, 2002; Larson, 2011). For example, early in the project, patch dynamics served as a metaphor to stimulate conversation between social and biophysical scientists. As a metaphor, it engaged the shared interest of all contributing disciplines in spatial heterogeneity. However, later, joint research was conducted which led to substantive products. HERCULES, the integrated land cover classification discussed above, is a fruit of the patch dynamics perspective that combines structures generated by social and biological processes in the urban mosaic (Cadenasso et al., 2007). Similarly, a patch dynamics perspective is operationalized in the spatial modeling of lifestyle and consumption patterns affecting environmental quality and management in the social realm. Substantial empirical research has resulted that combines social survey, measures of neighborhood cohesion, and demographic and economic data in a dynamic, spatial form. More recently, patch dynamics has been an opening for dialog between social and biophysical sciences and urban design. The substance has been architectural and design studio work employing this perspective (McGrath et al., 2007).

The Mix of Practical and Pure

The mandate of the National Science Foundation is basic research, along with an interest in the broader societal impacts of the projects it funds. The other main source of support, the USDA Forest Service, is a mission-oriented agency. Because of this combination of support, BES aims to mix practical and pure research. Indeed, awareness of the concerns of Baltimore area communities and agencies has shaped new research projects or has added practical dimensions to existing research projects. Interdisciplinary research on the presence, management, and condition of Baltimore's tree canopy has required understanding both biophysical features and its social origins and implications. Much of this research has been stimulated by desires of policymakers to move beyond the riparian zones to help diminish and improve the stormwater budget of the urban area. Indeed, this expanded extent of "riparian" management itself was stimulated by findings of functional impairment in the ecosystem services provided by the urban riparian zones (Cadenasso et al., 2008). While not all research in a long-term ecological research project will be practically applicable, a challenge remains to ensure that the project is open to the opportunity to discover both pure and practical outcomes, as well as to benefit from the new research that can emerge from this combination.

Novelty vs. Consistency

One requirement of integrated research is joint ongoing activity. As described earlier, such consistency is important to building a trusting community of researchers and constituents, as well as to develop fully shared frameworks. This is a challenge because of the pressure by funding agencies and by the researchers and practitioners themselves to begin new projects periodically or do new things. Successful integrated research cannot neglect consistency in favor of novelty, though both are needed.

One stimulus for novelty is the evolutionary nature of frameworks and guiding questions for research and application. For example, the original human ecosystem framework was primarily a product of the social sciences, with keen awareness of biological fundamentals. However, when this framework was applied to BES, one of the first outcomes was the addition of important features to the component of the framework that addressed the resource system. Newly highlighted were certain ecosystem processes and the important role of spatial heterogeneity and dynamics as components of the foundational resources for the human ecosystem (Pickett et al., 1997).

Research questions have also evolved as a result of interaction between the biophysical and the social sciences in BES. For example, early correlations were sought between demographic features, such as income, education, and ethnicity and national origin, and key aspects of the biophysical system, such as impervious surfaces and presence of woody plant cover (Grove and Burch, 1997). As the understanding of the urban system has deepened, the need to go beyond standard demographic data and to understand the spatial distribution of behavioral and group identity as drivers and responses to biophysical characteristics of the ecosystem has developed (Grove et al., 2006; Grove, 2009). Hence, more recent research has asked questions about market segmentation, that is, the consumption practices of different social groups in the metropolis. Similar integrated concern with land cover contributed to the establishment of the HERCULES land cover classification mentioned earlier.

Sustainability

One important stimulus for evolution in research questions is the changing perception of the hazards facing urban areas and the involvement of ecosystem services in cities. As a signal of these sorts of shifts, the growing interest of cities and urban areas in sustainability stands out. As a result of this major reorientation in the policy environment, the Baltimore Ecosystem Study has posed a new overarching research question to guide the six year phase of activity beginning in 2011: "What are the effects of adaptive processes aimed at sustainability in the Baltimore socioecological system?" It would have been risky to posit a particular set of future environmental conditions to study. However, the reality of the altered policy environment and the existing perceptions of hazard and services, along with perceptions that will emerge as the public discourse further engages with sustainability, can be used to organize and frame a new generation of research.

Broadening the Empirical Base

The information needed to fully understand integrated social–ecological systems over the broad extent of urban–rural interfaces is immense. For example, for watersheds and hydrology to live up to their integrative potential much finer resolution of the dynamics of water is required. Not only must large drainages that span the rural to urban transition be characterized, but data are also needed for smaller catchments that represent different social and land use types, or that have different combinations of social and biophysical properties. Indeed, to evaluate various management practices and local interventions in drainage and infiltration, parcel level or small clusters of yards must be evaluated hydrologically. To sample at such fine scales large amounts of instrumentation and person power are required. A second, related example is the ideal requirement for vegetation sampling. Remote sensing is useful for quantifying overall tree canopy cover, discriminating deciduous from coniferous canopy, and distinguishing grass or crop cover from other vegetation. However, to distinguish between species reliably, ground-based studies are required. Species or plant trait data obtained in fine-scale studies can address questions of support of animal biodiversity, the roles of exotic species, or successional trajectories in vegetation along the urban–rural interface. Furthermore, to account for species that are active at different times of year, multiple periods of sampling will be required.

Spatially refined data on biogeophysical functioning in human ecosystems are also required. Lysimeters to measure flow of water and the dissolved minerals and suspended particles it carries must be deployed across small contrasting patch types to document fully the loss or retention of important nutrients and pollutants. Similarly, atmospheric inputs of pollutants, such as particulates or nitrogen, must be assessed at medium to fine scales within different ranges of the urban–rural interface. Of course, modeling of distributions based on extensive stratified sampling is a complementary approach. However, even that requires relatively large numbers of samples for statistical reliability. The distribution of lead in residential properties in Baltimore City is an example. Samples from yards around brick versus frame houses, close and far from major transportation corridors, and dating from before and after the elimination of lead from paint and gasoline have been used to estimate potential exposure to lead (Schwarz et al., 2012).

A challenge remains in linking the fine-scale biogeophysical data on structure and function with coarser-scale surveys obtained through remote instruments. Strategies linking "pixels, plots, and parcels" will undoubtedly be important across many urban–rural interfaces (Grove, 2009). Stratifying the mosaics thus represented will require spatial refinement of common census-based data. For example, census blocks are delimited to comprise approximately 400 households. Consequently, these socially important data units are larger than the scale of many hypothesized driving relationships in social–ecological systems. Dasymetric mapping, in which characteristics of the land cover are used to apportion population features more finely than the spatial unit of an entire census block is one strategy available.

Theory for Integration

Much of the integration discussed above is in the empirical realm. However, theory also is a tool to promote integration. This is so because theory exposes the conceptual structure and assumptions that different disciplines, or even integrative teams, bring to a study (Pickett et al., 2007). Articulation of theory relevant to an integrated social–ecological structure or process alerts the members of a team to assumptions that may be in conflict across disciplines, to concepts that may differ even though the words used are the same, or to different strategies for building models. Furthermore, different disciplines involved in the study of urban–rural interfaces may emphasize normative intent to different degrees. Rigorous discussion of the theories each discipline employs, or the attempt to construct a unified theory for the integrative project itself may help expose normative assumptions. For example, theories of environmental justice may assume that equitable access to a decision-making process is a good to be achieved. Theories of ecosystem function may assume that increased richness benefits functional stability. Both of these assumptions can be used normatively, and that choice should be discussed and evaluated when such theories inform integrated research programs. Indeed, such discussion may lead to novel tests of fundamental assumptions that bear on an area.

Science and Design: Integration for the Urban Future

An important challenge for research at the urban rural interface is the integration with urban design. Contemporary urban design is considered to include the three professions of architecture, landscape architecture, and planning (Spirn, 2001). Because so many urban areas are growing in spatial extent worldwide, planning and urban design are quite relevant to integrated study across this interface (Alberti, 2008). Yet, the design professions of architecture, urban design, and planning contrast in important ways with the sciences. Designers intend to intervene in the structure and social programs in the places they target. In contrast, biophysical scientists generally study the world as it exists, and employ fine-scale interventions—experiments—as tools to elucidate causes of that structure or the dynamics by which the structures and functions can change. Perhaps the social sciences are intermediate, given the social good that often attends their research. In any event, as researchers, citizens, and designers desire to promote more sustainable cities, and indeed more sustainable socioecological systems throughout the range of the urban–rural interface, the interaction among these disparate cultures becomes an important opportunity for integration (Felson and Pickett, 2005). Designers have for a long time sought to produce new sites or projects, or restore and revitalize existing sites to better accommodate ecological processes and structures. However, the demand still exceeds the effort devoted to ecological design. Although some designers have a substantive understanding of urban ecology, most are relegated to using ecological metaphors in their work. There is a great opportunity for deepening the dialog between urban designers and socioecological researchers along the urban–rural interface. Sharing data, working on the same projects so that ecological monitoring and assessment can be built in to the management of buildings and sites, and even envisioning designs as experiments that expose effects of alternative aspects of a design are possible linkages. Here again, the ability to understand the normative goals of design compared to the goals of basic research can help smooth the integration.

Coda

Studying urban ecosystems presents great conceptual and practical challenges. However, meeting these challenges can help improve the quality of life for people living in cities, reduce the environmental impact of new excursions of urban life and structures into the rural fringe, and contribute to ecological and social revitalization of degraded or underserved human settlements across the globe. Improving the ecological knowledge about how urban and rural systems interact as integrated socioecological systems of regional extent remains an important goal. Furthermore, understanding how to interact with disciplines that contribute so much to the design and planning of human settlements along the interface can ensure that both new and existing ecological knowledge are best brought to the civic dialog shaping the ever-growing urban–rural interface.

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