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Landscape and Urban Planning 69 (2004) 369–384
LANDSCAPE AND URBAN PLANNING
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Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms

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Received 19 March 2003; received in revised form 3 September 2003; accepted 27 October 2003

Abstract

Urban designers, ecologists, and social scientists have called for closer links among their disciplines. We examine a promising new tool for promoting this linkage—the metaphor of "cities of resilience." To put this tool to best use, we indicate how metaphor fits with other conceptual tools in science. We then present the two opposing definitions of resilience from ecology, and give reasons why one is more appropriate for linking with design. Additional specific tools and insights that are emerging from, or being increasingly used in, ecology can further support the linkage with urban design. These include recognizing the role of spatial heterogeneity in both ecological and social functioning of urban areas, the integrating power of watersheds, social and ecological patch dynamics of cities, the utility of spatial mosaic models to capture function, the use of an integrated "human ecosystem" modeling framework, and the consequent perspective of metropolitan areas as integrated ecological-social systems. Three additional tools are related to the adaptability of people and human institutions. First is the recognition of a "learning loop" in metropolitan ecosystems in which people respond to and affect ecological change, the use of urban design as experiments whose ecological and social outcomes can be measured, and finally the potency of a dialog between professionals and citizens, communities, and institutions, to support both research and design. The metaphor of resilience, and its technical specifications, draw these diverse strands for linking ecology and planning together.

Keywords: Ecosystem; Ecological resilience; Integration; Paradigm; Urban design; Urban ecology; Urban planning

1. Introduction

The purpose of this paper is to explore two new tools to help improve the link between urban design and planning and ecology. As ecologists and social ecologists, we wish to share insights that have recently emerged in ecology that can promote better integration between the design and ecological realms. The first tool is a novel metaphor, which can build on the familiarity of both disciplines with other powerful metaphors. We will work with a new metaphor, "cities of resilience," proposed by an urban planner and an ecologist (Musacchio and Wu, 2002), that both disciplines can share. This will require us to recognize the importance of metaphor in urban design, and to explore the place of metaphor in the technical discourse of ecology. Resilience, as a metaphor, can help link ecology and planning, but first, the technical meaning of resilience must be clarified. The second tool for promoting linkage is the concern of both fields with the relationship between structure and function. Structure refers to the way systems are built, while function

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doi:10.1016/j.landurbplan.2003.10.035

refers to what they do in a particular context. We will extract key insights from the Baltimore Ecosystem Study, Long-term Ecological Research program (BES) that we believe will be valuable in helping ecologists and planners jointly define cities of resilience. The metaphor is common property accessible to both disciplines. This paper lays out a way to help build an effective interdisciplinary collaboration based on the shared metaphor.

As a metaphor new to both realms, cities of resilience may suggest images such as staying power, or flexibility, or adaptability. Thinking of cities in these terms is compelling and provocative because it emphasizes dynamics. Each of these ways to describe resilience can engage planners, ecologists, and the public. To explore the ecological implications of resilience, we must first outline the multiple layers of connotation inherent in resilience as an ecological concept. We will search for parallel layers of connotation in planning to advance the links between ecological science and the practice of urban design and planning.

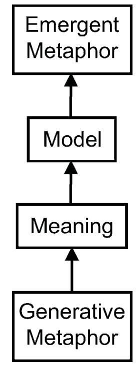

Fig. 1. The relationship of the three kinds of connotation of ecological concepts. Meaning refers to the basic, most general definition of a concept. Models are the quantitative, graphical, or structural translations of the concept to specific real or hypothetical situations. Metaphors are the images that stimulate creation of technical concepts or represent them in informal, non-technical discourse. Metaphor, an act of imagination, can stimulate specific technical meaning(s). Theoretical tools convert general, fundamental meanings to operational models. Once research has applied or refined models, the new understanding can generate new metaphors to inform public dialog or the interaction with scientists outside the specialty responsible for the meaning and model. In this figure, only generative metaphors are shown. Emergent metaphors would result from the models that apply the basic, general meaning to different actual cases.

2. Kinds of connotation in ecology

Any technical term in ecology has three kinds of connotation: meaning, model, and metaphor (Fig. 1; Pickett and Cadenasso, 2002). The meaning is the core definition of a concept that can apply to any appropriate situation or instance. We can use the concept of "ecosystem" as an example (Pickett and Cadenasso, 2002). The core definition or meaning of the term, ecosystem, is an assemblage of organisms interacting with the physical environment within a specified area (Tansley, 1935; Likens, 1992). This core definition does not imply a particular scale, or any particular kinds of organisms, or stability, or equilibrium, or isolation. Because the core definition is so remarkably free of assumptions, application to a specific site or purpose requires researchers to specify additional characteristics. This specification resides on the second layer of connotation.

The second kind of connotation is that of models. Models translate the core meaning to a real or proposed situation (Fig. 1). A model is a representation of a system, which identifies the components of the system, its spatial and temporal bounds, the interactions among components, and the kind and range of dynamics that the interactions can experience (Pickett et al., 1994).

Models, as tools to transfer meaning to specific situations, can be equations, experiments, graphs, or flow charts, among others. A very general model expressing the ecosystem concept appears in Fig. 2A. Such a model indicates some of the key kinds of features any ecosystem model might contain: a boundary encompassing the system of interest, a focus on some material or energy flux, identification of key compartments that the material or energy might flow between, identification of processes governing the flux, and finally, input and output from the system as a whole. An example of a much more specific translation of the ecosystem concept is an experimental model established in the Hubbard Brook Valley, New Hampshire (Likens and Bormann, 1995). The Hubbard Brook Ecosystem Study encompasses the catchment of a small stream, along with the forest vegetation, microbes, other organisms, and soil (Fig. 2B). The study seeks to understand what controls the input, transformation, and output of nutrients in this watershed. A

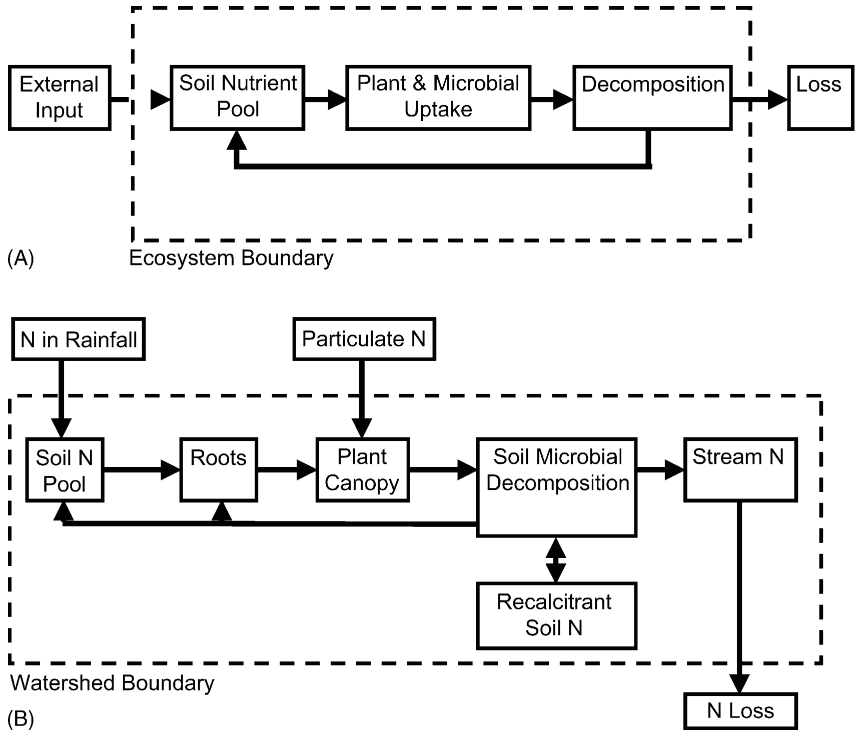

Fig. 2. Illustrative models derived from the ecosystem concept. (A) A general, simple terrestrial ecosystem model. The model focuses on nutrient flow, and includes a boundary, a term for inputs of nutrient from outside the system, and a term for nutrient loss from the bounded system. Within the system, nutrients can be stored in a soil pool, transferred to microbes or plants, or released from plant tissues by decomposition. Once nutrients are released via decomposition, they may be lost from the system or recycled within it. (B) A more specific ecosystem model relevant to a forested watershed. The basic concept of ecosystem is specified more completely by stating the kind of boundary, assuming nitrogen as the nutrient of interest, and by recognizing two different kinds of inputs of nitrogen (N) from outside the watershed. In addition, based on knowledge from real ecosystems, such as the forest at Hubbard Brook, the model recognizes that N inputs can be processed through the soil or through the tree canopies. Nitrogen (N) can be released by decomposition, but some N can also be stored for long periods in organic matter that is hard to decompose. Finally, N can be lost from the stream. The model suggests that the sizes of the pools (roots, canopies, etc.) and the transfers among them determine the amout of N stored in or lost from the system. Note that this is not a complete ecosystem model, but merely illustrates the kinds of detail that must be specified to translate the concept of the ecosystem to a site in the natural world.

main research task has been to discover and quantify the pathways and controls of nitrogen fluxes in that watershed (Likens and Bormann, 1995). Nitrogen is an important limiting factor in forests, and this study has been instrumental in understanding how vegetation disturbance and succession, acid rain, and microbes control the availability of the nitrogen and the sustainability of the forest (Fig. 2B).

An example of an ecosystem model that might be especially relevant to planning is one being developed for the Baltimore metropolitan region. This ecological model, central to the Baltimore Ecosystem Study, includes not only the sorts of components and interactions contained in the conceptual model for forested watersheds at Hubbard Brook, but several additional, anthropogenic factors and interactions necessary for understanding an urban ecosystem (Machlis et al., 1997; Pickett et al., 1997). In the case of BES, several urbanized, suburban and rural watersheds are investigated, along with the streams and infrastructure, soils, air, wild and cultivated plants, domestic and wild animals, microbes, buildings, human population, and various kinds of linked human institutions. Familiar fluxes of water, nutrients, energy, and organisms exist in Baltimore in the same way that they do in Hubbard Brook. Of course, how these fluxes are modified

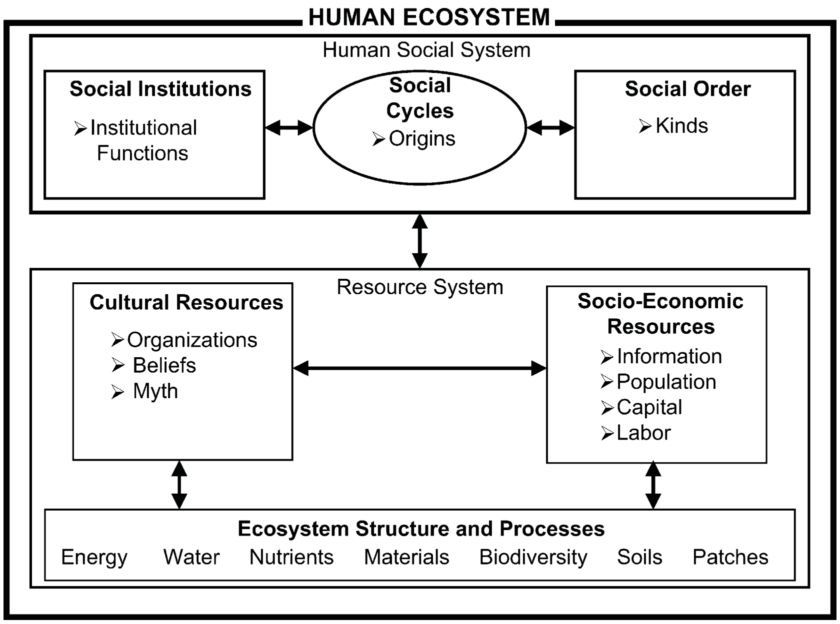

Fig. 3. The human ecosystem framework. This suite of processes and factors includes the complete range of entities and interactions in general terms that would have to be considered when constructing a specific model of a human ecosystem. Each general factor or process listed in the framework can itself be broken down into more specific processes and interactions. The components of the social system are listed in the text. The components of the human ecosystem framework would be combined into models that had the same form as those shown in Fig. 2. The flows and stocks in such a case would involve both biogeophysical materials and energy, and social and built capital and human influences. Modified and simplified from Machlis et al. (1994) and Pickett et al. (1997).

by human behavior, institutional actions, and infrastructure must be understood. The additional fluxes in the Baltimore ecosystem model can include financial capital, human capital, social capital, and built capital (Folke et al., 1994; Grove and Burch, 1997; Fig. 3).

The third kind of connotation of the ecosystem concept is its metaphorical implications (Fig. 1). Because metaphors are figures of speech in which one thing is taken for another, different thing, such figures of speech lead to highly visual analogies that spur creativity when applied in new situations. Note that metaphor may stimulate the creation of a technical concept, or metaphor may emerge from the use or application of a technical concept. Therefore, metaphors can be generative or emergent (Fig. 1). For the concept of ecosystem, both kinds of metaphor exist. The generative metaphor is perhaps connectedness, or diversity of components. The emergent metaphorical connotations of the ecosystem concept are many, and often contradictory. Ecosystems are viewed as machines, or organic entities, or cybernetic code (Golley, 1993). They are viewed as either fragile or robust structures (Cronon, 1995). Connectivity, adaptability, integrity, or complexity are other emergent connotations of this concept. In public or informal scientific discourse, these connotations of the term ecosystem can be used to represent personal or group values. It is extremely important to recognize the difference between creative and provocative metaphors and the rigorous meanings or models that advance scientific understanding of ecological concepts.

3. Metaphor as an integrative tool

Metaphor is a powerful tool for creating new ideas and syntheses, which can suggest how to use an idea or approach developed in one realm in an entirely different realm (Pickett, 1999). Therefore, metaphor is an apt tool for seeking connections between planning and the science of ecology. Metaphors already play a large role in both planning and science, which we illustrate briefly.

Metaphor has great power in planning (Thompson and Steiner, 1997; Spirn, 2001). There are several famous examples. One, "The City Beautiful" focuses on the aesthetics of grand buildings and their landscaped settings, and, while it was a progressive reaction to the negative urban features of the industrial revolution, it expressed dominance over nature (Johnson, 1997). Another important metaphor in planning is "The Garden City," in which large productive and recreational green spaces are zoned as an isolated counterpoise to crowded commercial, residential, and industrial sectors (Johnson, 1997). These metaphors heralded important movements in urban planning and design, and frame continuing currents and debate (Johnson, 1997; Meyer, 1997; Woodward, 1997; Ndubisi, 2002).

In addition to the example of ecosystem metaphors already given, the science of ecology employs other metaphors. For example, the term "evolution" was adopted from common speech, where it indicates an unfolding or rolling out of some form. A somewhat less comprehensive example of metaphor is that of succession. In ecology, succession refers to the change in the structure and composition of a plant community or an ecosystem with time. Although ecologists no longer see it as a process of monarchical replacement of one ruling plant community by another, the metaphor was crucial in arousing ecologists to the pervasiveness and regularities of change in nature. Many other ecological terms have a vernacular, metaphorical origin, and were upon first use more evocative than technical. Among these are "community," "disturbance," and "competition." Each of these metaphorical terms has acquired a rigorous, ecological meaning, and has come to stand for a body of data and theory that constitutes a well-developed branch of the science (e.g. Karr, 2001).

Scientific terms and terms from planning will all have the three levels of connotation summarized as meaning, model, and metaphor. It is important to know which level of connotation is being used by participants in a dialog and what core meaning, or model structures are implied. Metaphorical dialog must be followed by at least some level of specification of models emerging from a clear, core definition. We have presented examples of translating metaphors to technical meanings and then to models in the Hubbard Brook Ecosystem Study and the Baltimore Ecosystem Study (Fig. 2B). Therefore, the first insight to support linkage of ecology and planning *is the acknowledgment of multiple layers of connotation for ecological terms, and the need to choose an appropriate level for dialog among ecology and planning* (Box 2). Indeed, the theory of design and planning called for by some planners (e.g. Corner, 1997) should facilitate interdisciplinary dialog. The next section will explore how the metaphor of cities of resilience can be used to help link ecology and planning. The final section of the paper will propose that designs incorporating resilience constitute the models in this new integrated realm of ecological design.

4. Resilience as an integrative metaphor

We will focus on resilience in the ecological realm because that is the source of its technical meaning. In order to link ecology and design, the contradiction in the definitions of resilience in ecology must first be resolved. The contradiction grows out of two paradigms from which the definitions emerge. These paradigms may be labeled equilibrium and non-equilibrium (Pickett et al., 1992).

In the extreme equilibrium view, resilience is seen as the ability of systems to return to their stable equilibrium point after disruption. The entire theoretical apparatus and connotation of the term is focused on stable equilibrium conditions. But this conceptual apparatus has suffered greatly in the past 30 years, to the point of being reduced to a special case or unusual situation among real ecological systems (Pickett et al., 1992; Pulliam and Johnson, 2001). The opposing, or rather more inclusive, non-equilibrium view (Box 1) treats resilience in a way that is more useful for urban planning and design because it is more dynamic and evolutionary. Under the non-equilibrium paradigm, resilience is the ability of a system to adapt and adjust to changing internal or external processes (Holling, 1973; Gunderson et al., 1995). The emphasis is not on reaching or maintaining a certain end point or terminal condition, but on staying "in the game." If designers desire to employ the "new ecology" (Steiner, 2002), it is important to recognize which ecological concepts in fact imply and embody the new, non-equilibrium paradigm (Pickett and Ostfeld, 1995).

Box 1. Major points of the contemporary, nonequilibrium paradigm of ecology. Based on Pickett et al. (1992). The classical, equilibrium paradigm is characterized by the opposite cases of each of the points below.

1. Ecological systems are open. Energy, according to the second law of thermodynamics, necessarily flows through ecological systems. However, the contemporary paradigm recognizes that systems may also be open to the flows of chemical materials, such as nutrients and pollutants, to organisms, to genetic information, and to environmental signals that affect the behavior of organisms. (Classical: Systems are materially closed.)
2. Ecological systems may be externally regulated. If systems are open to the flows outlined in point 1, then it may be that one or more of the factors that enters an ecological system from an adjacent or distant one may in fact be responsible for limiting or stimulating the processes in the system of interest. (Classical: Systems are internally regulated.)
3. Ecological systems may have multiple, or no, stable state(s). System openness and environmental variability may result in frequent or constant dynamics of systems. On certain coarse scales, ecological systems may be stable, but at fine scales, they may rarely be stable. Alternatively, shifting conditions and thresholds may cause systems to jump from one stable state to another. This point suggests that resilience in the evolutionary sense is a more appropriate criterion of persistence of ecological systems than stability or equilibrium. (Classical: Systems have a single equilibrium state.)
4. Ecological systems have probabilistic dynamics. Succession, the change in composition or structure through time, may not exhibit deterministic, fixed sequences of states. Shifts from one state to another may be stochastic. Historical contingencies and external events contribute to the probabilistic nature of change in systems. (Classical: Systems dynamics are deterministic.)
5. Disturbance, in the technical sense of events that disrupt physical structure of systems, may be a component of a system at a specified scale. Empirical evidence has abundantly shown that such physical disruptions are a major aspect of system dynamics. (Classical: Disturbance is an exceptional event in systems.)
6. Humans are part of ecosystems. Human individuals, societies, groups, and institutions all have been shown to have a major role to play in many ecosystems. Often the influence is in the form of past activities that have a persistent effect on soils, plants, or other major components of ecological systems. Sometimes the influence works at a distance, as when pollution is transported by ground water or air from upstream source areas. Of course, many areas of the globe are coming under direct human influence through logging, grazing, harvesting, pollution, urbanization, and agriculture. Models that take humans into account include them as integral parts of the systems at hand. (Classical: Humans are external to ecological systems.)

Resilience implies an additional important aspect of the non-equilibrium paradigm. Classically, ecologists were concerned with structures or the simple description of how system are put together. However, ecology has advanced by delving beneath the surface to expose the processes that make systems work. The concern with mechanism and process is labeled function in ecology. In a sense, the non-equilibrium paradigm focuses attention on processes and dynamics—function—rather than primarily on states and structures. Therefore the second insight from ecology is that *concern with resilience in the contemporary, non-equilibrium sense requires a concern for linking structure with function or process*. This insight from ecology parallels emerging concerns in planning (Ndubisi, 1997; Olin, 1997). However, several major metaphors from planning remain focused on the structure of urban systems. We outline two of these below.

The City Beautiful metaphor emphasized a structure consisting of heroic architecture within a passive backdrop of landscape (Johnson, 1997). This view was condemned because it neglected social heterogeneity and processes (Jacobs, 1962), and we find little evidence that the view included ecological perspectives or environmental processes either (Johnson, 1997; Johnson and Hill, 2001). Notable failures of the design paradigm associated with the metaphor of the City Beautiful confirm its social and ecological limits (Meyer, 1997). These failures include sterile office blocks, and dangerous public housing projects.

A second example is the structural approach of McHarg (1969) known as "design with nature." It is remarkable because it included assessment of biological, geological, hydrological, and other environmental and cultural features of a site to be planned, and it recognized the role of processes within most of these layers (McHarg, 1997). However, rarely were truly dynamic data available, and it is possible for the overlay approach to be conducted as a static exercise (Ndubisi, 1997, 2002). In addition, the linkages of processes between layers is uncertain (Vroom, 1997), and ecological data are only just now emerging in any volume to link even the biogeophysical layers effectively, especially in urban landscapes (Grimm et al., 2000; Pickett et al., 2001). It may seem unfair to complain about lack of attention to integrating processes in the structural design approach, given the state of ecology at the time of McHarg's early writings and even more recently. The systems ecology available for McHarg in 1969 was largely silent about spatial heterogeneity at the medium to small scales relevant to design, and had not progressed far in relating biological and physical processes with one another, much less with social processes. Therefore, the linkage of form or pattern with processes is the remaining task.

Many widely cited or classic books proposing the linkage between ecology and design emphasize the classical equilibrium paradigm. For example, Lyle (1999) use the deterministic succession and stable climax ideas from ecology. Importantly, he does indicate the controversy concerning climax and succession that was emerging within ecology when he first wrote in 1969. However, the classic versions of those concepts remained a part of his toolkit. More recently, Ndubisi (2002: 224) bases the ecological concepts he brings to the design discussion on a foundation of equilibrium: "Equilibrium is the fundamental force that drives the organization and maintains the stability of ecosystems."

5. Linking ecological and social heterogeneity and function

If planning and design are fundamentally about form and function, we may profitably examine parallels in ecology. Although this is easy in some ways because science investigates the structures it finds in the world and their functional significance, it is not straightforward. Ecology has a complex history of dealing with structure-function relationships. Because of the many layers of structure, and the manifold feedbacks between structure and function, the task of discovering the relationships is difficult.

As a descendant of biogeography, ecology has always dealt well with coarse scale heterogeneity—global patterns of plant and animal adaptation and distribution, or continental and altitudinal expressions of these same phenomena. However, the discipline has dealt poorly with heterogeneity at the fine scale (Cadenasso et al., 2003b). Models and explanations proposed under the classical, equilibrium paradigm emphasized or assumed uniformity of systems. Even landscapes on the scale of kilometers were not effectively addressed by ecology. Only in the 1980's did a conceptual framework to encourage investigation of the nature and significance of spatial heterogeneity on this scale emerge under the rubric of landscape ecology (Forman and Godron, 1986). However, once ecologists recognized the lapse, progress in filling the gap has been rapid (Pickett, 1998). Therefore, one of the key insights to emerge from contemporary ecology for our consideration is that *spatial heterogeneity can govern system function at any scale* (Pickett and Cadenasso, 1995).

The existence of heterogeneity invites consideration of its functional role. This is an active area of research in ecology (Pickett and Cadenasso, 1995; Pickett et al., 2000; Cadenasso et al., 2003a). We exemplify the nature of the integration of structure and function in a heterogeneous landscape using on-going work in BES (http://www.beslter.org). Our examples are arrayed along a continuum of increasing comprehensiveness and complexity and point to additional integrations relevant to the dialog with planning. We start with a relatively simple example of watershed structure and function, add spatially explicit and temporal dynamics to this perspective by using the concept of patch dynamics, and then add humans to the conceptual mix. Once humans have been incorporated into spatially heterogeneous and dynamic ecological frameworks, we will exemplify how ecologists deal with the fact that humans are involved in ecosystems as learning and active agents of change. We extract ecological insights for planning from each of these examples.

5.1. Watershed structure and function

The watershed is a concept that attracts different disciplines and practices, and hence provides an opportunity to link different perspectives, concerns, and expertise (Likens, 1984; Band et al., 1993; Costanza and Greer, 1995; Adams, 2001). Watershed studies range from those of ecology per se, which is exemplified by the Hubbard Brook study already mentioned (Likens, 1992), to studies incorporating social processes (Lee, 1992; Grove and Burch, 1997).

Watersheds are integrators of diverse processes, since overland and subterranean flow of water can accumulate nutrients, sediments, and pollutants downstream. Outfall from a watershed can indicate the net effect of processes occurring throughout the watershed (Likens, 1992). Many ecologists and hydrologists have exploited this feature of watersheds to advance the understanding of topics such as the amelioration or effect of acid rain, and the impact of different logging practices (e.g. Bormann and Likens, 1979). Such an integrative function of watersheds will work equally well in urban systems.

Civil infrastructure in some cases reflects watershed structure (Spirn, 1984). Indeed in Baltimore, the fact that the city encompasses three watersheds with efficient flow gradients is one explanation of why the city was among the last in the United States to install a modern sewer system (Boone, 2003). The sanitary and storm systems followed the primary drainages and subcatchments for their trunk and feeder lines.

The location of several of Baltimore's forested parks in large stream valleys reflects watershed structure, which is not surprising given the role of the Olmsted Brothers firm in the city park plan (Olmsted Brothers, 1904; cf. Spirn, 1984). With the grass roots efforts to protect one of these parks from a proposed Interstate highway in the 1970s, watershed associations were born in Baltimore. These associations, with the assistance of the Parks & People Foundation (www.parksandpeople.org), have promoted watershed-based management in Baltimore city parks (Burch and Grove, 1993; Grove et al., 1994, forthcoming). Thus, watersheds are a political and activist focus in the city.

The breadth of constituencies and professions that can use watersheds presents a pathway for linkages between planning and design and ecological science (Spirn, 1984). Recognizing the spatial heterogeneity within watersheds is important to understanding the ecological, social, and infrastructural functions of watersheds (Pickett et al., 1997; Grove and Burch, 1997). Watersheds are a specific instance of the broader ecological insight about heterogeneity mentioned earlier. Watershed studies in ecology lead to the insight that *watersheds have ecological functions that can be exploited in design and planning.*

5.2. Patch dynamics

Patches, or relatively discrete, spatially explicit areas, can be recognized on the basis of diverse criteria (Pickett and White, 1985). For example, patches in watersheds may be defined by contrasting capacities to shed or absorb water (Hewlett and Nutter, 1969; Black, 1991). The detailed, spatially explicit distribution of such contrasting patches within watersheds controls the function of the entire watershed (Bormann and Likens, 1979; Yair and Shachak, 1987). In urban areas, vegetation type and density, the nature and density of buildings, infrastructural and transportation pathways, are examples of biological and physical patches (Grove, 1996; Grove and Burch, 1997; Pickett et al., 1997).

Just as physical and biological phenomena can be discriminated as a patchwork in the metropolis, so can social ones (Logan and Molotch, 1987; Grove, 1996; Gottdiener and Hutchinson, 2000). Social heterogeneity is manifested in many ways. One example is the 276 recognized neighborhoods that exist in Baltimore City's 80 sq. mile area. Many of these neighborhoods have been remarkably persistent through time in spite of shifts in ethnic and economic characteristics of residents. Quantitatively, social heterogeneity can be assessed spatially using indices that take into account education, economics, and ethnicity, and using census block groups (Grove, 1996). A related way to dissect social patterns is through novel uses of market analysis, US Census geographies, and surveys of environmental decision making. Increasing spatial resolution can be achieved by detailed survey of the actual environmental decisions that households make.

Water, air pollution, different types of capital, and so on can accumulate or move across the mosaic of patches in the biophysical template. How the physical and social allocation mechanisms are arrayed in space and how they constrain or permit those fluxes, and what factors control the flux across the metropolitan patch mosaic are important questions motivating on-going research (Pickett et al., 1997; Grimm et al., 2000). Quantitative models of patch structure in urban watersheds have shown that the explicit configuration of surface types is a better predictor of water flow than the average composition of the watershed (Brun and Band, 2000).

Once scientists, citizens, and planners recognize the spatial heterogeneity of an area of interest, there remains an additional important concern. Not only is the pattern of spatial heterogeneity important, so is the fact that the spatial pattern can change and shift over time. The temporal dimension of patch change is a key aspect of the patch dynamics perspective in both urban and wild lands. In wild lands, patches change as a result of resource accumulation or loss, growth of organisms, natural disturbances, and succession. Wild landscapes can thus be visualized as a shifting mosaic of patches—a patch dynamic landscape. This approach has been important in understanding the diversity of organisms, and the function of ecosystems over coarse scales (Bormann and Likens, 1979; Pickett and White, 1985; Pickett, 1998). In metropolitan systems, there are also examples of patch dynamics. For example, woody vegetation in certain neighborhoods correlates with a socioeconomic index; however, the correlation is with the tree population and the social characteristics of the preceding decade, not the current census (Grove, 1996; Vogt et al., 2002).

We expect many more cases of joint social-ecological patch dynamics to emerge with continued study. For instance, we hypothesize that residential patches that contain mixed sizes of single dwellings as well as row houses will experience a higher probability of vacancy due to disparities in income necessary to maintain the different sizes of structures.

The insight that emerges from ecology concerning patch dynamics is that *spatial heterogeneity, function, and temporal change can be integrated into a spatial mosaic model*. We expect that this approach will be helpful in evaluating the integrated effects of contrasting spatial arrangements of the green and built elements that concern planners and designers (Grove and Burch, 1997). What happens when people are added to the mix?

5.3. The human ecosystem framework

To bring ecological understanding to bear in metropolitan systems, a framework that expresses social and economic processes on an equal footing with bioecological and earth sciences processes is needed. In the BES, we have adopted the human ecosystem framework (Machlis et al., 1997) to play this integrative role (Pickett et al., 1997). As a framework, it suggests the factors and phenomena that need to be selected to construct detailed or specific models of the structure and function of metropolitan ecosystems. The models must account for the spatial heterogeneity and dynamics suggested by watershed studies and patch dynamics. But the models must also account for factors that ecologists only rarely consider. Perhaps the most radically different suite of factors that must be included are the social resources and social processes (Fig. 3) that will help govern integrated human ecosystems (Grove and Burch, 1997; Machlis et al., 1997). Social resources include information, human population, financial capital, and labor. Cultural resources are also part of human ecosystems, and they include organizations, beliefs, and myths. How these resources are allocated depends on the social processes or mechanisms in the system (Parker and Burch, 1992). Burch and DeLuca (1984), Parker and Burch (1992), and Machlis et al. (1997) have discussed how the unequal allocation of critical biogeophysical, social, and cultural resources is significantly affected by social order as expressed in social identity (ethnicity, age, gender, class, etc.), norms of behavior, and hierarchies of wealth, power, status, knowledge, and territory. These are linked to institutional functions focusing on justice, health, faith, commerce, education, etc., through temporal cycles based on dynamics of individual physiology, environmental change, organizational maturity, and institutional effectiveness. It is the rich potential for feedbacks among these phenomena that make metropolitan ecosystem so complex and unpredictable. However, the connections can be teased apart to explain observed dynamics or to give context to alternative design scenarios.

The lesson from the human ecosystem framework is that *the metropolis is an integrated ecological-social-infrastructural system*. The models derived from the human ecosystem framework are not a matter of humans versus nature, but humans and ecological processes combined into a reciprocally interactive network (Fig. 3). The power of this framework can be illustrated with hypotheses currently being investigated in BES.

One component of BES asks whether different lawn fertilization practices in various neighborhoods are reflected in nitrogen export into streams draining those neighborhoods (Law et al., accepted). A second research question asks whether social patches based on marketing clusters are congruent with structural patches based on vegetation and built structure (Grove et al., submitted). From a broad perspective, we can ask, do structural patches that have different rates of change exhibit different social characteristics? Alternatively, we can inquire whether patches with different structures exhibit different degrees of social resilience or dynamics. We do not imply functional determinism in these correlations, and it is important to remember Jacobs's (1962) criticism of the strict environmental determinism implied by the City Beautiful assumptions. In an "if you build it, they will come" mindset, it was assumed that the physical structure of the built environment was sufficient to determine a functional social good.

The human ecosystem framework may look like a shopping list of system components. However, it is crucial to realize that the most significant feature of the framework is the fact that it points to the interactions among particular natural, social, and cultural components of the metropolis. This recognition prompts ecologists to be concerned with how people use and behave in the metropolitan ecosystem in a spatially explicit way (Gottdiener and Hutchinson, 2000).

5.4. The learning loop

People are by definition a part of the metropolitan system. They are individually and institutionally curious, engaged, responsive, and reactive components of the metropolitan ecosystem (Berkowitz et al., 2003). How can ecologists study the metropolitan ecosystem and communicate the results without potentially affecting the future state of the system? They can not. Because it is possible for people to use new ecological knowledge, and the values inferred from that knowledge as a spur to action, ecological research in the metropolis must recognize that it is a part of the system it studies. Research, therefore, should not try to avoid the connections between people, learning, and changes in the system. The insight relevant to linking ecology with planning and design is that *human perception, learning, and resultant actions are a part of the human ecosystem*. Therefore, one of the major research questions in BES is "How can people use an understanding of the metropolitan area as an ecological system to improve the quality of their lives and the environment downstream?" In other words, do BES and other ecological research make Baltimore more resilient?

To answer this question, we can consider social changes, economic dynamics, and planning and management actions as interventions akin to the experiments of laboratory science. Of course, there is necessarily not the control and replication that would exist in a lab, or even in an agricultural experimental plot. However, if the interventions have a strong effect, and if different interventions exhibit different mixtures of strong effects, they can be used as vehicles for learning. The insight from ecology here is that *planning and management interventions have ecological consequences that can be measured and communicated*. Monitoring for adaptive management has become a widely recognized strategy in ecological applications (Allen and Hoekstra, 1992). The use of monitoring and subsequent evaluation of societal interventions is a powerful, but underutilized tool (Grove et al., 2003). Designers are increasingly recognizing the need for monitoring the effects of a plan once put in place (Ndubisi, 1997; Adams, 2001). Therefore, partnerships with designers and planners should take advantage of the opportunity to monitor the effects, not only in aesthetic or design terms, but also in terms of biogeophysical and social processes. The best use of this partnering would of course be to refine either ecological measurements, the nature of the design in question, or the parameters of future designs to which the experience is relevant. Designs incorporating the concept of resilience are in fact the models

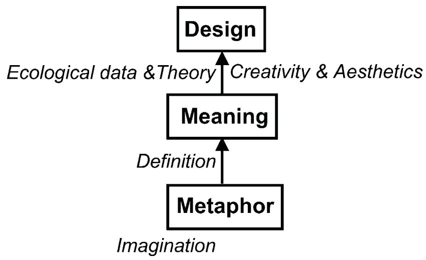

Fig. 4. A schematic for translating the metaphor of resilience to generate urban designs. The imaginative act of creating and accepting the metaphor of resilience can be shared by ecologists and urban designers. The definition relevant to urban design is chosen from among those available in ecology and supported by ecological theory, the non-equilibrium paradigm, and data from many studies. The creation of designs for urban ecosystems or sites within large urban systems combines insights from ecological theory and data with the creative and aesthetic work of designers. The resulting models are in fact designs for urban spaces that take into account ecological processes suggested by the contemporary paradigm and data, along with the concerns of designers and constraints of the political and social context. This paper does not present specific designs, but presents this framework as a template for the interdisciplinary process that would be followed.

of the integrated realm of ecology and urban design (Fig. 4).

We have taken as a useful model for research in inhabited areas the practice of participatory action research (Whyte, 1984; Field and Burch, 1988; Whyte, 1991a,b; Berkowitz et al., 2003). The approach admits that the people themselves have knowledge, of the system and their own actions, that will help understand the structure and dynamics of the human ecosystems being studied (Vayda, 1993). Benefits of the approach, which we have seen in BES, include better communication of research results to constituents, education of ecologists about important features of human ecosystem structure and function, and education of citizens about the nature and practice of science. The insight is that *dialog with community partners is more effective for research design and communication of results than "outreach" ex cathedra*. This does not mean that pure scientific research should be set aside in favor of a contractual approach, but that the benefits of mutually respectful dialog are important for science in metropolitan areas (Berkowitz et al., 2003). Ecologists are only beginning to explore participatory action research. They have much to learn in applying this strategy adopted from social sciences and rural community development. It is extremely costly in terms of money, time, and commitment, and there are few ecological models or resources available for ecologists to pursue this strategy.

6. How to proceed

This paper has explored a provocative metaphor to promote the interaction of the science of ecology and the practice of urban design. Interaction of disciplines can be enhanced by using either theory or practice. The process begins with the theoretical linkage based on resilience and supports practical designs incorporating the concept of resilience and the ecological insights (Box 2) needed to achieve resilience. The actual steps to accomplish include these:

1. Recognize resilience as a metaphor that both ecologists and designers can share.

Box 2. Summary of tactical insights promoting dialog between ecology, planning, and design.

1. Acknowledge multiple layers of connotation for ecological and social terms, and the need to choose an appropriate level of connotation for dialog among ecology, social science, design, and planning.
2. Concern with resilience in the contemporary, non-equilibrium sense, requires a linked concern of structure with function or process.
3. Spatial heterogeneity can govern system function at any scale.
4. Watersheds have ecological functions that can be exploited or at least must be understood in planning.
5. Spatial heterogeneity, function, and temporal changes can be integrated into a spatial mosaic model.
6. Human perception, learning and resultant actions are a part of the human ecosystem.
7. Planning and management interventions have ecological consequences that can be measured and communicated
8. Dialog with community partners is more effective for research design and communication of results than "outreach" *ex cathedra*.

2. Acknowledge the technical definition of resilience as incorporating ecological, social, and economic processes that permit the continued adjustment and self-organization of urban systems.
3. Articulate the ecological insights about processes that lead to resilience (Boxes 1 and 2). This constitutes an initial theoretical structure that can be shared by ecologists and designers.
4. Establish ongoing dialog within multidisciplinary teams comprising ecologists, social scientists, and designers. Long term dialog is required to ensure that the understanding of the shared theoretical base is deep. It is not sufficient to merely share common terms and language.
5. Identify potential design projects that can engage the multidisciplinary teams.
6. Exploit the learning loop by implementing design projects in collaboration with communities or clients.
7. Close the learning loop by quantifying change in ecological processes and by measuring social impacts resulting from the implemented designs. Communicating the effects to the public and decision makers constitutes part of the learning loop. Continued monitoring will be necessary as the projects mature, environmental effects accumulate, or social understanding of the project changes.

This series of steps takes the technical meaning of resilience as the core of a promising theory to unite design and ecology. It uses the metaphorical layer of the concept to initiate dialog and to reach a common understanding of the phenomenon. Based on this shared, if preliminary, theoretical base, design projects can be jointly undertaken. These projects will constitute the models that translate the shared theory from the conceptual realm to practice (Fig. 4).

7. Caveats

What might go wrong with this approach? We are proposing a theoretical exploration for improving the link between urban design and ecological science. One might argue that the worst that could go wrong is constructing a theoretical bridge that never supports the traffic of practice. There is a real danger that the articulation of theory from ecology and from design will be so divergent that it will be difficult, if not impossible, to build effective linkages between them. For example, design theory includes aesthetic as well as the empirical and conceptual dimensions that it clearly shares with scientific theories (Pickett et al., 1994). How to translate the aesthetic concerns of designers in a way that preserves their subtlety and engages scientists is an open issue. The emphasis on the technical core of resilience based on ecological science should not exclude the aesthetic and creative components so necessary for successful design.

A second caveat is that the concept of resilience should not be misappropriated to suggest that any change in urban systems is acceptable or desirable. From an ecological perspective, changes that exceed the evolutionary, physiological, or migratory capacities of crucial components of ecosystems are potentially catastrophic (Pickett and Ostfeld, 1995). These limits must be kept in mind when designing and constructing interventions in urban systems. The existence of ecological limits suggests that there may be parallel limits in the social, economic, engineering, or aesthetic realms that are all so crucial to the function and implementation of urban design. We acknowledge such limits, but their exploration is beyond our scope here.

A final caveat is the great effort needed to accomplish a resilience-based linkage of ecology and design. The educational needs on both sides of the disciplinary divide are great. There is also the constraint that may be placed on the approach by poor public apprehension of the ideas and the ways practice might have to evolve to accommodate resilience. Not only must teams of ecologists and designers be engaged in continuing dialog aimed at implementing designs that contribute to resilient cities, they must help educate their constituencies to any novel requirements of this integrated approach to design for ecological resilience.

Members of other disciplines and constituencies may identify other caveats to this approach. Our purpose here is to acknowledge that researchers and practitioners intent on putting this approach into action will have hurdles to overcome.

8. Conclusions

We have explored ways to improve the integration of ecology, and urban planning and design. Better integration has been desired for a long time (Lyle, 1999). There are new insights from ecology that have developed over the last several decades that can ensure the broadest and most up to date framing of the integration. We suggest that metaphor is the first bridge to help synthesize the disciplines of ecology, social science, and urban design. Metaphor is evocative and suggestive, but it is often silent about details of structure and mechanisms of function. Therefore, an initial step of adopting a central metaphor as a synthetic tool is to realize the technical refinements needed to use the image. First a meaning, or core definition, must be articulated; second, modeling strategies to translate the abstract definition to specific cases must be used.

We adopt the metaphor of cities of resilience (Musacchio and Wu, 2002) as the tool to stimulate synthesis between planning and ecological and social sciences. This metaphor suggests flexibility over the long term. Indeed, the technical definition of resilience now gaining ascendancy in ecology hews closely to this metaphorical connotation. Resilience is the ability of a system to adjust in the face of changing conditions. This view is significantly different from an earlier interpretation in ecology of resilience in a narrow engineering sense. The old view considered resilience to be the ability of a system to return to an equilibrium condition after disturbance. Clearly this older definition of resilience is not suitable to cities and urban regions, which have continued to change throughout their histories.

The metaphor and technical definition begin to point toward the improved integration of ecology, social science and planning. This field remains an open frontier, though both designers and ecologists have pointed out the need for such integration (e.g. Pulliam and Johnson, 2001; Forman, 2001). What is needed to consummate the integration? From the science, specific models are required to determine exactly how to measure resilience, and to specify linking processes and structures generated by planning, and by the social and ecological approaches to cities. We do not present those specific models here, but have presented general insights and concepts that can inform those specific models. These insights are also the likely components of integrated planning-ecological models that emerge from linked ecological and social science perspectives. Ultimately, integrated models would take the form of ecologically informed designs or plans generated by interdisciplinary teams. We compile the insights for easy reference and to stimulate further interaction between planners and ecologists (Box 2). In the urban design professions, designs act as the models embodying the core concept of resilience. The next step is to determine whether planning and design theory suggest additional ones, or different ways to cast those that we propose. On this basis, teams can then target actual design opportunities. Resilience can be a core tool for pursuing this integration.

Acknowledgements

We are grateful to Drs. Laura Musacchio and Jianguo Wu for inviting us to participate in their ground-breaking symposium on Cities of Resilience. Design colleagues Brian McGrath, Victoria Marshall, Richard Plunz, and Joel Towers, of the Columbia University Graduate School of Architecture, Planning and Preservation, have been instrumental in advancing our understanding of the design fields. Support was provided by the National Science Foundation through the LTER program to the Baltimore Ecosystem Study (DEB 9713548), with additional support from the USDA Forest Service. Preparation of our contribution to the symposium was supported by the Herberger Center of Arizona State University. This is a contribution to the program of the Institute of Ecosystem Studies with partial support from the Mary Flagler Cary Charitable Trust.

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