CHAPTER 5.5

Linking Social and Ecological Systems

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5.5.1 Introduction

On 16 November 2005 a water sample was taken from an urban stream in a metropolitan area in the southern United States and tested for the presence of *E. coli*. Although water samples from this and other streams in the metropolitan area frequently registered over 15,000 colonies/100 ml, this particular sample is unique in that it registered a reading of 70,000 colonies/100 ml, 350 per cent greater than the 200 colonies/100 ml—the Environment Protection Agency's standard for streams. The fetid floodwaters in New Orleans from Hurricane Katrina, which had a contamination level of 10,000 colonies/100 ml and attracted considerable public attention, were cleaner than this stream at the time of sampling.

Although a number of factors can contribute to this high reading, the stream consistently failed to meet water quality standards throughout the year. In addition, children from the local neighbourhood often played in the stream. Yet, presentations on water quality issues and potential health hazards did not raise any concerns among the citizenry, news outlets, and policy-makers.

Obviously, there appears to be a disconnection between social and ecological systems as reflected by the lack of concern by residents, natural resource managers, and decision-makers to the degraded stream conditions. This disconnection suggests the following question: How are social and ecological systems linked in urban landscapes and how does one begin to examine that linkage? In this chapter, we explore the linkage between the ecological and social systems of urban landscapes. First, we examine two metrics—sense of place and land cover—that have been used to integrate social and ecological systems. Second, we examine how system models have been used to link ecological systems with social systems. Third, we introduce the concept of complex adaptive systems (Gunderson & Holling 2002), as it may apply to urban landscapes, and finally we present a socio-ecological model (Morse 2007), based on complex adaptive systems and structuration theory (Stones 2005), as a means to link social systems with ecological systems.

5.5.2 Socio-ecological integrators

Westley *et al*. (2002) eloquently discuss how ecological and social systems are quite different and that the systems may not be as congruent as ecologists would like them to be. There are several reasons for this difference. Ecological systems are characterized by time and space. Social systems are too characterized by time and space, but there is also a third dimension—'structure of significance' (Westley *et al*. 2002). Structure of significance refers to the ability of humans to construct and manipulate symbols, principally words, thus collectively inventing a reality that may or may not reflect true conditions. Human actions and decisions are influenced by this structure of significance. In our water example, conditions may not be perceived by individuals as badly as the actual condition of the stream, thus no action. Although there is ecological change, as reflected by water quality, there is no social response.

This does not mean that social and ecological systems cannot be linked in an urban landscape. For example, the Baltimore Long-Term Ecological

Research program (LTER) has taken a patch approach to characterize social and ecological systems (Pickett *et al.* 1997). Pickett *et al.* (1997) proposed that by defining the urban landscape through social and ecological patches one can overlay the different patch types and examine how social and ecological systems are related. To accomplish this approach, Grove *et al.* (2006) used PRIZM, a marketing classification system, to define social patches and vegetation cover to characterize ecological conditions of riparian habitat, private lands, and right-of-ways. PRIZM categorizes people into lifestyle clusters based on household education, income, occupation, race/ancestry, family composition, and housing (Claritas 1999).

Grove *et al.* (2006) report that standard variables, such as income and education, did not explain variations in vegetation cover of the selected habitats. Likewise, they observed that population density was not a good predictor of vegetation cover, a social metric often used to characterize social conditions. Grove *et al.* (2006) did observe that lifestyle behaviour was the best predictor for vegetation cover of private lands, and housing age was significantly associated with vegetation cover for each of the selected habitats. They also reported that social stratification was a better predictor of potential vegetation cover, whereas lifestyle behaviour was a better predictor of present vegetation cover.

The aspect of scale is especially problematic in socio-ecological research. For example, at the fine-scale level, individual decisions affect the context in which ecological structure and function occur. Yet, many of the policies regulating management decisions are implemented at the broader scale. Grove *et al.* (2006) illustrate this interplay of scale of fine-scale decisions and broad-scale management with respect to social systems. Lifestyle of landowners influenced not only the vegetation on their property but also on right-of-ways (managed lands), which are governed by a broad-scale management plan.

The use of PRIZM information to define social patch types may be effective as a site specific analysis; however, cross-site analyses may be limited without further characterization of environmental attitudes, perceptions, and behaviours of marketing classes regionally, nationally, and internationally. Do the environmental attitudes, perceptions, and behaviours of a marketing class vary regionally? Are they the same across a nation? Do they differ among nations? With further research, databases like PRIZM may provide insights into how social and ecological systems are integrated in urban and urbanizing landscapes.

Cross-site analyses provide an opportunity to compare how social and ecological systems are similar or dissimilar across urban areas. Both sense of place and land cover types have been used in cross-site analyses to evaluate how socio-ecological systems vary among urban areas, and will be examined in greater detail below.

5.5.2.1 Sense of place

The Millennium Ecosystem Assessment (2003) defines 'sense of place' as one of the non-material, cultural services provided by ecosystems. It follows then that when ecosystems or landscapes are altered to a measurable degree, the net gain or loss to cultural services should be also altered, as would other provisioning or regulating services like food, water, or climate. Arguably, a construct such as sense of place is more difficult to gauge than other services because the former depends to a greater extent on human perception. Still, these ecosystem services are articulated strongly in instances of ecosystem and landscape change. Bengston *et al.* (2005) remark: '[a]t the local level, ... the core of the debate about sprawl ... is the emotional impact people experience when they lose places in their own communities they feel deeply attached to'.

Sense of place is both a conceptual and an empirical approach to assess humans' emotive and cognitive, non-tangible, cultural connection to place (Relpf 1997). Fundamentally, sense of place refers to people's interpretation of a place and their resulting identification with the same. The domains of sense of place include place attachment (self-identity related to place), place satisfaction (attitudes toward place), place meanings (descriptive of why the place is important), and place characteristics (environmental attributes) (Stedman 2002, 2003). We assume that sense of places varies by perceiver and that attachments are imparted to a place based on people's experiences with places. Meanings are not necessarily inherent in a place but are assigned and may vary accordingly among individuals or groups, much like Westley's *et al.*'s (2002) significance of structure. Although we regard sense of place as socially constructed, we also assume that there are more generally held interpretations of place that can be discerned by socio-demographic groups or other meaningful subgroups. Because of the subjectivity of sense of place, it is also assumed to be dynamic, continually changing and evolving based on structural drivers such as changing demographics, political influence, or natural change. Place definitions, even at a given point in time, are open to multiple interpretations, but once a standard has been established it is repeatable; hence, its inherit application to cross-site analyses (Jorgensen & Stedman 2006). Sense of place, however, has its own set of problems with respect to standardization due to the very definition of 'sense of place,' that its complexity resists exact definition, and attempts to quantify it may miss the point.

Senseo fpla cem easurement

Measurement of sense of place and related constructs (place attachment) use both quantitative and qualitative methodologies, although qualitative or phenomenological approaches are common. Entrikin (1991) discusses the fundamental problems of accounting for human perceptions as variables in place analyses. The subjective meanings, feelings, and symbols which comprise sense of place are difficult to adequately quantify with standard positivistic measures such as Likert scales. Entrikin (1991) proposes the use of open-ended narrative as a method of assessing place perceptions and the use of conjoint analysis.

Still, a rich literature exists on quantitative means of assessing place-related constructs (primarily place attachment) dating back to the early 1990s—for instance, Williams *et al*. (1992) seminal work on the construction of a place attachment scale, and more recently Williams and Vaske's (2003) use of confirmatory factor analysis to examine the generalizability and validity of a two-dimensional scale of place attachment; and Jorgensen and Stedman's (2001) attitudinal scale representing three commonly accepted dimensions of sense of place and place attachment: place identity, attachment, and dependence.

Ecological beliefs and environmental values are potential modifiers of individual land-use choices and of an individuals' sense of place (Jorgensen & Stedman 2006). One way of quantifying these values is to map them spatially through place-based mapping (Brown 2005). Mapped landscape values will provide the link from social understanding to ecological analysis of specific places on the landscape. The mapped landscape values will be supplemented by a more nuanced understanding of ecological attributes that are being developed for the satisfaction domain of sense of place and the detailed information on ecological beliefs and values and behaviours. Through use of the ecological data, we can provide realistic scenarios for potential ecological change and directly link them to potential changes in landscape values and individuals' sense of place. Realistic 'what if' scenarios can be developed to understand trade-offs between sense of place, landscape values, and ecological change.

A number of efforts have been made towards mapping landscape values (Brown 2005). The most developed of these focuses on landscape values and activities and relates them to sense of place. Specific ecological values attributed to the landscape are rather limited in this literature and it is expected that the area needs to be expanded to facilitate integration with ecological data. By mapping landscape values there is the potential for suitability analysis, conservation planning, identification of local knowledge, and hot spot identification (Brown 2005). An additional benefit is the inclusion of landscape values in development scenarios to assess effects on social systems through the measurement of place attachment by validity and generalizability of a psychometric approach (Brown 2006). When combining mapping with a method for calculating potential conflict (Manfredo *et al*. 2003), the approach could provide a very useful guide for regional planning and conservation of natural areas and future development, as described by Yli-Pelkonen and Niemelä (2005).

5.5.2.2 Land cover

Humans transform a landscape for their habitat, a process known as urbanization. These transformations have been studied extensively to assess their effects on ecosystem patterns and processes—ecology in the system—and have been illustrated in this text, chapters in this book, and elsewhere (e.g. McDonnell *et al*. 2009). The use of that landscape by humans is called 'land-use' and is generally classified using a classification system devised by Anderson *et al*. (1976). How humans manage that land-use creates a variety of complex land covers such as yards, gardens, vacant lots, forest remnants, and agricultural plots (see Pauleit and Breuste, Chapter 1.1; Ellis *et al*. 2006). Although additional research is needed to link land cover to social structures and patterns, we hypothesize that these fine-scale attributes, both ecological and social, can be used to characterize a 'signature' of a landscape. These signatures would reflect specific ecological structure associated with specific social structure along the urban–rural gradient.

Fine-scale mapping to link social and ecological structure is not new. Biotoping has been used extensively for fine-scale mapping of habitats in urban landscapes, but is very labour intensive (see Pauleit and Breuste, Chapter 1.1; Sukopp & Weiler 1988). More recently, biotoping has been linked to social context to evaluate the effect of context on biodiversity (Cilliers and Sibert, Chapter 3.2; Cilliers *et al*. in review). Again, this approach is very labour intensive and may not be suitable for cross-site comparisons because of differences in social context. Cadenasso *et al*. (2007) have developed a fine-scale mapping protocol, HERCULES, that links infrastructure with vegetation cover, and have demonstrated its usefulness in predicting water quality as compared to an Anderson classification. Although Anderson land-use classification was not developed for predicting water quality (the use of per cent of impervious surfaces may be an easier method than the spatial mapping required by HERCULES), HERCULES begins to address the issue of infrastructure and its effect on ecosystem processes. Like biotoping, HERCULES is labour intensive and is rather unwieldy because of the numerous types of patches generated. Nonetheless, for small catchments, the protocol may be useful in linking ecological structure and function with social patterns and processes when supplemented with social characterizations. Quantifying error, a necessity for cross-site comparisons, may be problematic (see Ellis 2000). Similarly, Grove *et al*. (2006) used fine-scale analysis to identify what social attributes affect public land management, but their approach may not have worldwide applicability because of the use of PRIZM, a marketing classification system for the United States, and the costs associated with purchasing PRIZM data.

To couple human and natural systems, attention must be given to both land-use (human use) and land cover (biophysical condition) and their spatial and temporal dynamics and autocorrelation (Rindfuss *et al*. 2004). Obviously, multidisciplinary teams composed of natural, social, and spatial disciplines are necessary. Of these disciplines, social characterizations of a land parcel may be the most fluid. Rindfuss *et al*. (2004) observed that a land parcel may change ownership, be borrowed or rented, have multiusers with different purposes, and may have multiple jurisdictions affecting it. Yet, from a spatial perspective, the patch and its boundaries may not change with changing social context, and if change does occur, there may be a time lag before it is recorded by the observer. Rindfuss *et al*. (2004) further report four issues that occur with linking natural, social, and spatial attributes over time: 1) aggregation and inference problems, 2) land-use pixel links, 3) data and measurements, and 4) remote sensing analysis. Aggregation and inference problems are scale issues. Patterns observed at the aggregate level of county or district may not exist at the household level (see Robinson 1950) and similarly patterns at the household level may not be the same operating at an aggregate level. Rindfuss *et al*. (2004) state that the solution is rather simple '…the level of aggregation in the measurement needs to match the level of aggregation in the hypothesis being examined'. In other words, link your methodology to your research question.

The challenge of linking land-use to pixels has three issues: 1) the fundamental differences between the way data are collected on people and pixel, 2) the spatio-temporal implications of the data collections, and 3) analytical problems associated with combining issues 1 and 2 (Rindfuss *et al*. 2004). As previously mentioned, the parcel and its boundaries may not change spatially over time but ownership and use may. Obviously, longitudinal studies are needed to ascertain how sociological attributes and their organization change within a parcel. The challenge of linking land-use to pixels echoes also in the type of data and measurements taken. Intuitively, this issue is driven by the research question. What sociological measurements are needed and how are they expressed on the ground? Ground truthing for both sociological attributes (e.g. through surveys and interviews) and biophysical features of the parcel, needs to be done congruently. An important aspect of this component is data quality, not only with respect to the individual disciplines but also interactions between disciplines (Rindfuss *et al.* 2004). Unfortunately, such a data error structure has not been developed.

Finally, remote sensing analysis issues are of particular concern for temporal analyses when using multiple scenes from various time points. 'False change' errors may occur with mis-registration of maps and textural differences (Ellis *et al.* 2006). These problems can be corrected through estimating changes in the ecological map across the sample cell (Wang & Ellis 2005). Another error is disagreement between interpreters, which can be minimized through training and testing quality assurance at different intervals of study. This testing will yield a measure of interpreter error which can be used to give a conservative estimate of prediction error for the reported spatial changes.

Even with the issues presented, fine-scale analyses (e.g. land cover) may be the best opportunities to link social and ecological data and enable cross-site comparability. For example, Ellis *et al.* (2006) used land-use and land-cover data, interpreted from high spatial resolution (<1 m) imagery, for six 1 km^2 sites, two in the United States (urban) and four in China (agricultural villages), to compare long-term ecological changes within densely populated landscapes. Using their protocol, one could modify land-uses and land covers for urban landscapes only. By appropriately overlaying sociological data, one can be begin to evaluate fine-scale changes sociologically and ecologically. For instance, a wealth of sociological data existed for New Orleans neighbourhoods before Hurricane Katrina impacted the city, and a considerable amount of data has been collected after the storm. By coupling that data with high resolution imagery and on the ground sampling, one can begin to examine the resiliency of social and ecological structure in response to a trauma. Similarly, many cities in Europe are losing their population because of low birth rates and emigration. This dynamic change provides the opportunity to study stability of social and ecological systems in a changing economic environment.

5.5.3 Modelling social-ecological systems

In 1998, the US National Science Foundation established two long-term ecological research sites—Baltimore, Maryland, and Phoenix, Arizona—to study urban landscapes. One of the desired outcomes from these programmes was to link social-economic systems with ecological systems (Redman *et al.* 2004). For ecological systems, the LTER network in the United States focuses on five core research areas: pattern and control of primary production, spatial and temporal distribution of populations selected to represent trophic structure, pattern and control of organic matter, pattern and movement of inorganic material, and patterns and frequency of disturbances (http://www.lternet.edu/coreareas). By having similar core research areas, LTER sites can conduct cross-site comparative studies of ecosystem structure and function across a vast array of bioregions. With the advent of the urban LTERs, similar core research areas have been proposed for sociological patterns and processes within the LTER network. Core areas are demography, technological change, economic growth, political and social institutions, culture, and knowledge of information exchange (Redman *et al.* 2004) (Table 5.5.1). Redman *et al.* (2004) propose that the human and ecological components of urban landscapes interact across multiple spatial and temporal scales and these interactions are mediated by land-use, land cover, production, consumption, and disposal.

An initial approach to link social and ecological systems was to adapt the human ecological model proposed by Machlis *et al.* (1997) to urban landscapes (Pickett *et al.* 1997). In their model, Machlis *et al.* (1997) provide a detailed list of socio-economic attributes that define social systems and link those attributes to natural resources. The model, itself, does not identify how each attribute interacts, but

Table 5.5.1 Redman *et al*. (2004) proposed the following social patterns and processes to serve as core research areas for social analyses within the National Science Foundation Long-Term Ecological Research Network

Demography: the growth, size, composition, distribution, and movement of human populations.
Technology change: the accumulated store of cultural knowledge about how to adapt to, use, and act on the biophysical environment and its material resources to satisfy human needs and wants.
Economic growth: the sets of institutional arrangements through which goods and services are produced and distributed.
Political and social institutions: enduring sets of ideas about how to accomplish goals recognized as important in a society. For instance, most societies have some form of family, religious, economic, educational, health, and political institutions that characterize its way of life.
Culture: culturally determined attitudes, beliefs, and values that purport to characterize aspects of collective reality, sentiments, and preferences of various groups at different scales, times, and places.
Knowledge and information exchange: the genetic and cultural communication of instructions, data, ideas, and so on.

rather leaves the identification of linkages to the user. For example, Pickett *et al*. (1997) modified Machlis original model by enhancing the biophysical resources to represent ecosystem patterns and processes, thus creating the framework to evaluate the effect of social structure on ecosystem structure andfun ction(Fig. 5.5.1).

Another modelling approach has been to link social drivers with ecological systems. Alberti (2008) identifies important socio-ecological drivers and recognizes the importance of spatio-temporal elements (Fig 5.5.2). In her conceptual model, ecosystem patterns and processes are linked directly to social patterns and processes through relevant interactions and feedbacks. Other models also have been proposed. For instance, Grimm *et al*. (2000) developed a conceptual scheme that integrates ecological and social systems (Fig. 5.5.3). What is particularly interesting about Grimm *et al*.'s (2000) approach is that the feedback loop within the social system is directly linked to land-use and ecosystem patterns and processes. In other words, they propose that in order to study social systems within an urban landscape, knowledge and information about the ecological and social systems is a prerequisite, thus directly linking social patterns and processes to ecological patterns and processes. Yli-Pelkonen and Niemelä (2005) have applied Grimm *et al*.'s (2000) model to guide urban planning in making recommendations for biological conservation of natural areas within an urban landscape. A more detailed description on how each of these models differ is described by Alberti (2008).

These models tend to be structural in their orientation, focusing on system level patterns and processes such as institutions, demographics, policies, and land-use patterns, and are known as system models. They often require detailed enumeration of causes and functional representations, and assume a linearity across a spatial scale (Parker *et al*. 2003). In general, these models are primarily biocentric—focusing principally on how ecological components are affected, this is to say the ecology *in* urban landscapes. In general, they do not account directly for the effect of the decision-making process or social drives on social patterns and processes. The research focuses principally on how urbanization, through different socio-economic drivers, affects ecosystem patterns and processes. That is not to say that socio-economic components are not identified and recognized as being affected too (see Grimm *et al*. 2000), but rather that the feedback mechanisms of how ecological systems are changing socio-economic systems are generally not quantified. For instance, in our water quality example, we can identify and quantify those anthropogenic factors creating the condition leading to degraded water quality, but we have not identified changes in social responses to this condition. This is understandable considering ecologists and biologists are using the models to study ecological patterns and processes under different land management conditions and social contexts—the ecology *in* urban landscapes.

Another set of models defining socio-ecological systems are called agent-based models. This set of models focuses on individuals or agents and their decision-making processes and actions (Parker *et al*. 2003). Agents are perceived to have control over

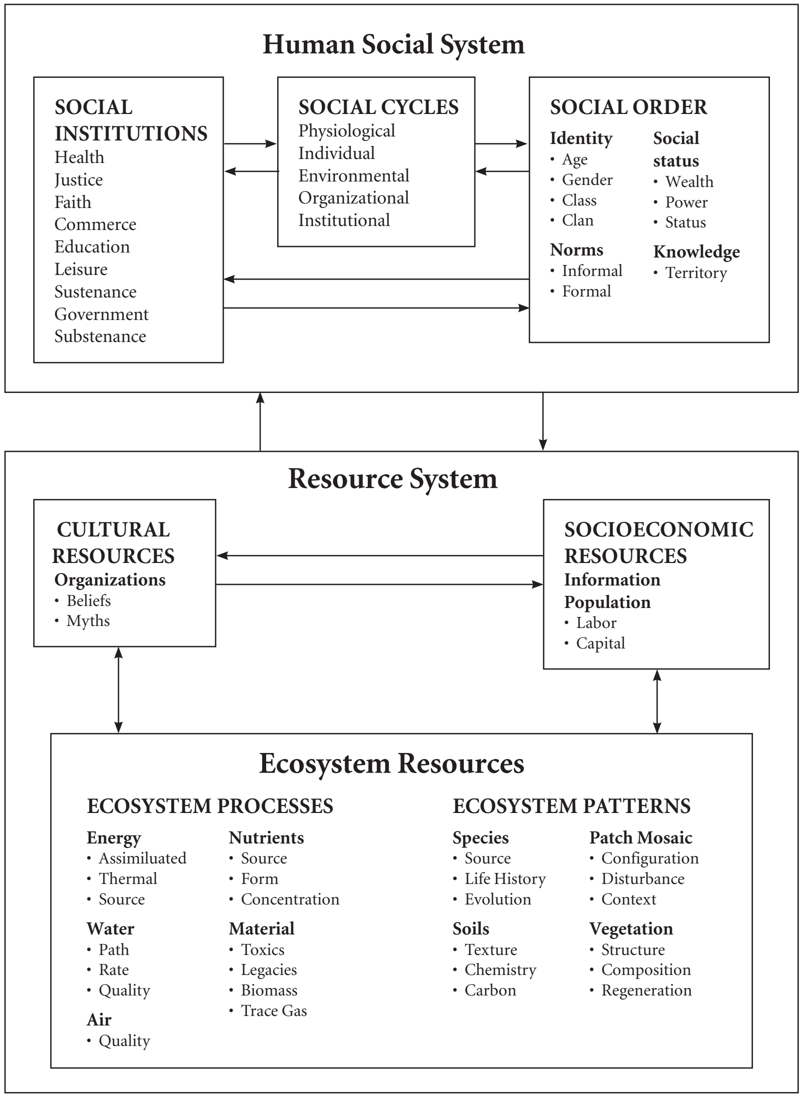

Figure 5.5.1 A conceptual model illustrating components within a human ecosystem and general linkages between those components, as proposed by Pickett *et al*. (1997). With kind permission from springer Science+Business Media

their actions and behave according to some model of decision-making, often some form of rational choice theory from economics. These models can be used to explore emergent patterns from individual human interactions between themselves and with the environment (Alberti 2008).

A third approach has begun to integrate system- and agent-based models, thus bringing together autonomous human agents and structural drivers, creating multiagent system models (Parker *et al*. 2003). Institutions, policies, and other social systems and ecosystem resources are seen to both enable and constrain the agent's actions, on the one hand, while also being the products of previous human actions and intentions (Morse 2007). For instance, Morse (2007) used an agent-based model to identify how policy was used to influence individual decisions on land-use and land cover and how the actions they

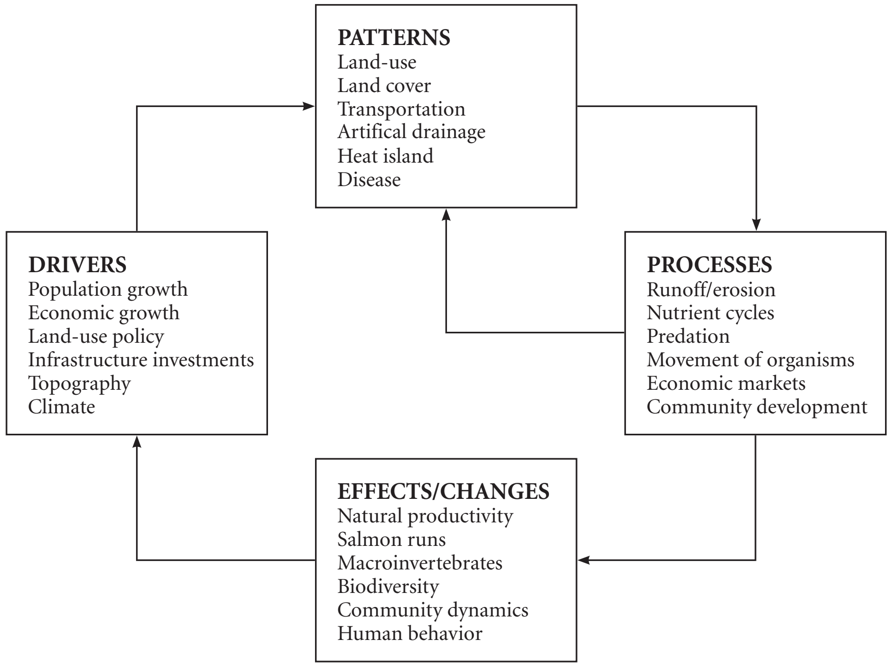

Figure 5.5.2 A conceptual model representing the relevant interactions and feedback of a socio-ecological system for urban ecosystems, as proposed by Alberti (2008). With permissin from The University of California Press

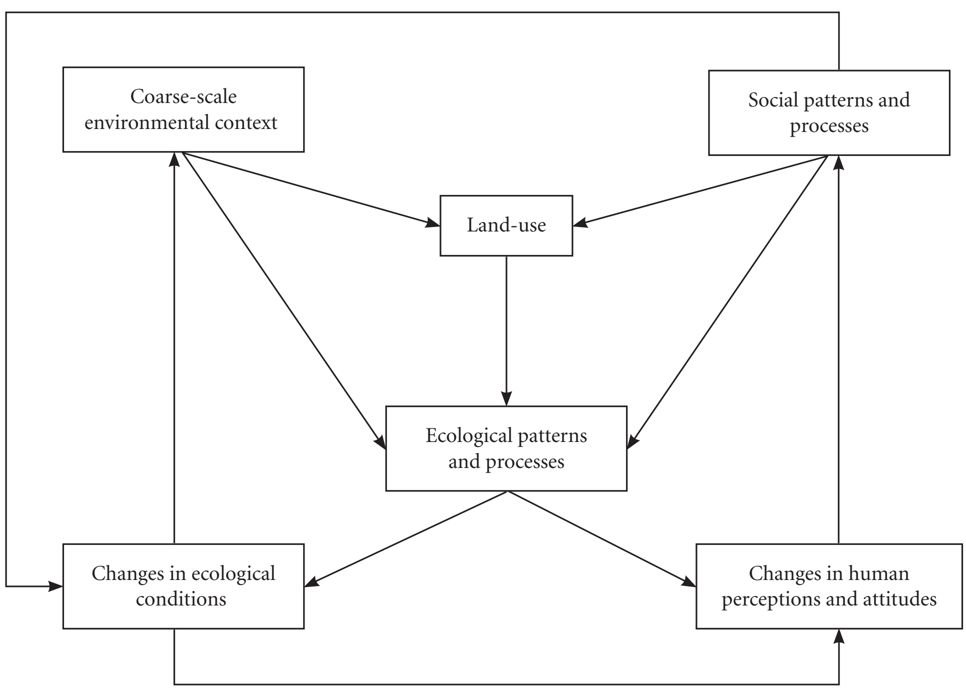

Figure 5.5.3 A conceptual scheme for integrating social and ecological systems in urban landscapes, as proposed by Grimm *et al.* (2000). With permissin from The University of California Press

took affected landscape patterns in an agrarian landscape in Costa Rica. A critical feature of this kind of model is to link the decision-making process across multiple levels in a dynamic manner that allows for understanding of decision-making within a changing structural (social and ecological) context. Even more importantly, this type of agent–structure–agent model allows for understanding of feedback that links changing ecological conditions to decision making. How do actors learn from past decisions? What information is taken into account when making decisions? Is ecological information taken into account? If it is, where did this information come from? How accurate is the information? How do we change the structures that influence future decisions? In essence, how do we respond to environmental feedbacks?

5.5.3.1 Complex adaptive systems

The processes of structural change to both social and ecological systems are examined by focusing on the cyclical process of human actions and interactions with the environment. The approach is based on the premise that urban landscapes are complex adaptive systems (see Gunderson & Holling 2002). In complex adaptive systems (CAS), the interactions of lower level components result in emergent patterns at higher levels that, in turn, feedback to influence future lower level interactions (Levin 1998). It is through this cyclic process of interactions and feedback that CAS self-organizes, often into nested systems (Levin 1998). CAS are also characterized by high levels of uncertainty, cross-scale interactions, threshold effects, and the possibility of multiple equilibria (Gunderson & Holling 2002). With a foundation in CAS, it is clear that understanding the feedback between and within social and ecological systems is critical if we are to manage for the resilience of these systems and their sustainability. Adaptive environmental assessment and management was developed as a flexible approach to address uncertainty and to provide a framework for active learning (Gunderson & Holling 2002). One of the central tenets of adaptive management is learning, and the learning is dependent upon processing of information in a formalized manner through experimentation, monitoring, and assessment (Gunderson 1999). But is all the information available? With the inevitability of surprise in CAS, is it even achievable? Is the information applicable or useful to human actors managing the system? How do different actors or decision-makers translate the information into actions? Before we continue the discussion on CAS, we need to expand our understanding of CAS by linking social and ecological systems in a Structuration of Complex Adaptive Systems (SoCAS) framework (see Morse 2007).

Structurationo fC omplexA daptiveSys tems

Central to a SoCAS framework are elements of structuration theory from the social sciences (Stones 2005), those of complex adaptive systems outlined above (Levin 1998; Gunderson & Holling 2002), and the theory of hierarchical patch dynamics (Wu and Loucks 1995) from the ecological sciences (Morse 2007). Both social and ecological theories are used to provide guidance because the drivers of these systems operate differently across spatial and temporal scales. Human actors act with foresight, reflexivity, and can communicate those ideas into the future, while ecosystems do not (Westley *et al.* 2002). For the framework, the social and ecological CAS mirror each other and are linked at the point where human actions and interactions with the environmento ccur(Fig. 5.5.4).

Structuration theory frames 'the interaction of structure and agency across scales [that] must be the centerpiece of a dynamic understanding of people–environment interaction' (Scoones 1999). Structuration theory avoids both an overly objective structural approach and an exaggerated emphasis of subjectivist, agent-based approaches by focusing on their interaction (Stones 2005). Human action is viewed as a continuous flow of conduct (Giddens 1984). Structure is seen as both 'the medium and outcome of the conduct it recursively organizes' (Giddens 1984). Structure enters into the constitution of the agent as a medium (internal structure) and from there into the practices that the agent produces as an outcome (external structure) (Stones 2005). Structures that are the outcome of one period of conduct (actions, activities) become the medium for the next round of agents' conduct (Stones 2005). Through recursive social conduct,

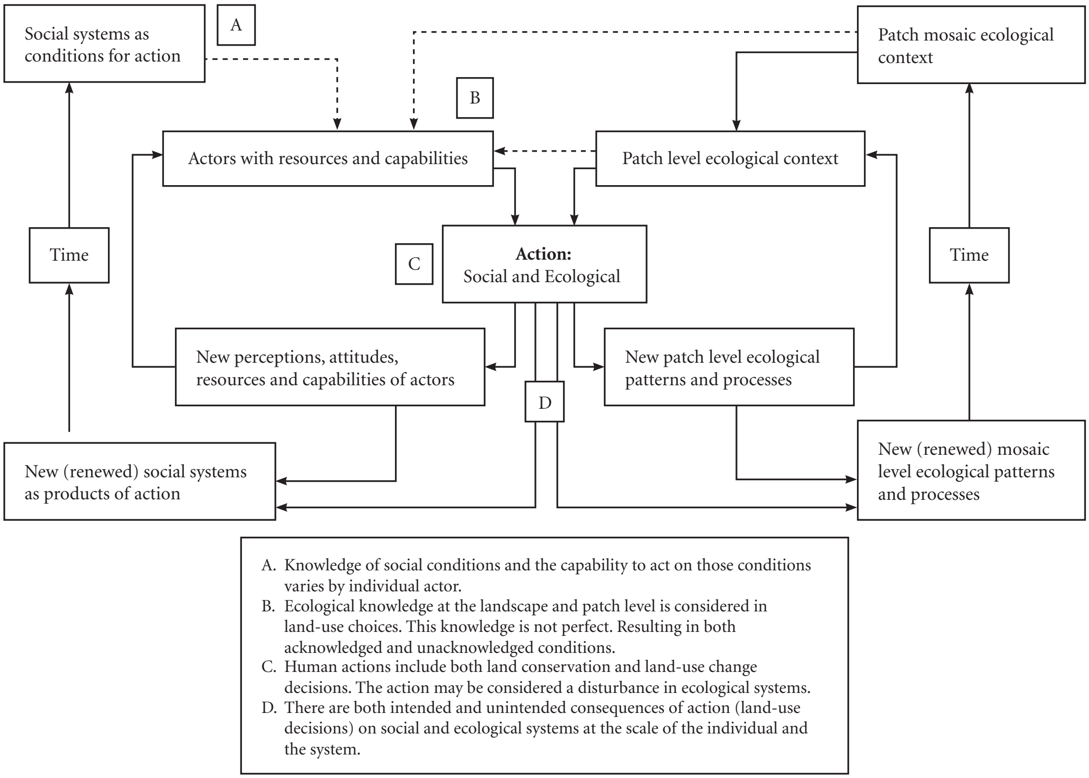

Figure 5.5.4 A conceptual model linking social decision-making processes with landscape dynamics to characterize the effect of land-use on social and ecological systems. This model is nested hierarchically within larger systems. With permission from The University of California Press

structures influence the activity of individuals, who in turn, transform or reaffirm those same structures constantly producing and reproducing society (Kondrat 2002).

Social systems (e.g. markets, governments) can be thought of as the patterns of social relations, or regularized social practices, that stretch across time and space produced by the process of structuration (Giddens 1984). They are the complex, entrenched, and powerful networks of relationships, behaviors, beliefs, interactions, rules, and resources, and are both temporally and spatially contingent (Kondrat 2002). Furthermore, they are integrated with other social systems hierarchically, across space and over time. Structures are considered to be both enabling and constraining of agents actions (Giddens 1984).

The model represents several areas where information is an input for the decision process (Fig. 5.5.4). Some of this information is ecological (B) and is not always perfect (dashed lines). Other information reflects the extent to which the decision-maker knows about external social structures and how to 'make things happen' within the system (A). The decision-maker takes action based on this knowledge (A, B) and incorporates their capabilities (resources at their disposal) to take action.

The black box of actor decision-making in Structuration includes, 1) their motivation to action, 2) the rationalization of action and knowledge, and 3) their ability to reflexively monitor their action (Giddens 1984). Motivations are the wants and desires of an individual and are their overall plans for conduct. Rationalization of action includes the agent's knowledge and how to proceed to obtain their intended outcomes. This knowledge is not perfect, however, and there is always the possibility of unacknowledged conditions and unintended consequences. Reflexive monitoring of action includes the agents' continual monitoring of actions and the consequences of their actions, and of the actions of others. This monitoring can be for both social and environmental consequences. This understanding of the individual's decision-making process matches nicely with that of adaptive management. The focus on knowledge provides a framework to emphasize conservation learning, the use of information, and the development of an ecological aesthetic. 'As knowledge about both social and ecological systems is often imperfect and the cumulative and cascading consequences of our actions within and across both systems are extremely complex and difficult to predict, explicit identification of these knowledge systems (or lack thereof) is a critical feature for a framework of linked social ecological CAS' (Morse 2007). Our model, and the others using this integrated approach, are well-adapted to capturing the interdependencies, heterogeneity, and nested hierarchies among agents and their environments characterizing urban landscapes (Parker *et al*. 2003). Parker *et al*. (2003) provides an excellent review of the application of multiagent system models to simulate land-use change.

5.5.4 Summary

We began this chapter by presenting a scenario involving a highly contaminated stream and the lack of political or environmental response to it. We ended the chapter by discussing ways in which to model social and ecological data. During this course, we presented different techniques and models currently being used to evaluate the integration of social and ecological systems. Throughout the discussion, the underlying assumption is that the ecology *of* the system can be derived for urban settlement along an urban to rural gradient only through long-term monitoring of both social and ecological components across multiple scales. Through the long-term monitoring of social and ecological systems, we will be able to build into these models the nuances of the complexity of our urban systems, thus potentially linking changes to social patterns and process to ecological patterns and processes. In doing so, we begin to take the necessary steps to identify factors affecting the sustainability of urban landscapes.

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2011