Enhancing the Resilience of Human-Environment Systems: A Social Ecological Perspective

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ABSTRACT
Resilience studies build on the notion that phenomena in the real world should be understood as dynamic social ecological systems. However, the scholarly community may not be fully aware that Social Ecology, as a conceptual framework, has a long intellectual history, nor fully cognizant of its foundational theory. In the article, the authors trace the intellectual roots and core principles of Social Ecology and demonstrate how these principles enable a broader conceptualization of resilience. We then illustrate how the resulting notion of resilience as transactional process and multi-capital formation affords new perspectives on diverse phenomena such as global financial crises and. adaptation to resource strains in marine and agricultural ecosystem. A social ecological analysis of resilience enables the study of people-environment transactions across varying dimensions, time periods, and scales. Furthermore, in its openness to experiential knowledge and action-research, the Social Ecology framework coheres well with participative-collaborative modes of inquiry which traverse institutional, epistemological, and scale-related boundaries.

Keywords: social ecology, environment-behavior transactions, resilience, social capital

INTRODUCTION

The first decade of the 21st Century has witnessed a succession of strikingly turbulent and disruptive events at geologic, climatic, and sociopolitical levels—from extreme weather events such as epochal hurricanes and floods, geologic disruptions epitomized by the Indian Ocean and Sendai earthquakes and tsunamis, to the 9/11 Terror Attacks, ongoing wars in Iraq and Afghanistan, ethnic genocide in Darfur, popular uprisings in several Arab countries during 2011, and the global economic recessions of 2008 and 2011 (Stokols et al. 2009). Reflecting on the succession of calamitous events that have occurred in recent years, scholars and policy makers from a variety of fields have begun to question whether humans' capacity for protecting the near-term resilience and longer-term sustainability of the earth's fragile ecosystems has been inexorably surpassed by converging environmental and societal perturbations that are now beyond our control (Gunderson and Folke 2011, Schoon et al. 2011).

Owing to the enormous complexities inherent in mapping the boundaries, energy flows, and cumulative outcomes of human-environment systems at multiple scales (e.g., ranging from local environments and their community contexts to larger and more encompassing entities such as regional and global ecospheres), researchers from the behavioral and environmental sciences increasingly are embracing social ecological models as a framework for conceptualizing and potentially managing the resilience and sustainability of human-environment systems (Berkes et al. 2003, Folke 2006, Peterson 2010). An important reason for the prominence of social ecological models in recent discussions of resilience and sustainability is that they emphasize certain core assumptions that enable broad-gauged analyses of the complex and dynamic interplay among biological, environmental, and sociopolitical components of human ecosystems, spanning multiple time intervals and local as well as global levels (cf., Stokols 1992, Redman et al. 2004, Ostrom 2009). Thus, the broad scope of social ecological models and their emphasis on key assumptions and methods drawn from complex systems theory are well suited for analyzing human resilience and sustainability during an era marked by profound environmental and societal disruptions (Von Bertalanffy 1950, Maruyama 1963, Emery 1969).

However, resilience scholars may not be completely aware of the long history and deep conceptual foundations of the social ecology paradigm. It is our conviction that resilience studies can be considerably advanced through a deeper appreciation of this well-developed and evolving conceptual framework, which incorporates analytic strategies that add value to those routinely employed by resilience scholars.

In this article, we briefly trace the emergence and core themes of social ecology as a basis for understanding and enhancing the quality of people-environment relationships. We then demonstrate how the deliberate application of social ecological principles to the analysis of human-environment transactions can yield rich new insights into the meaning of resilience and sustainability. We take as a starting point the definition of resilience proposed by Walker, Holling, Carpenter, and Kinzig (2004) as "*..the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks* (p. 2)." Maintaining resilience through strategic adaptability is an important prerequisite for ensuring the longer-term *sustainability* of a human-environment system. In addition to maintaining the viability of a system, sustainability also connotes the capacity of current generations to preserve and enlarge the stock of presently available resources so that they remain accessible to future generations as well (cf., Roseland et al. 1998).

A daunting challenge facing analyses of resilience and sustainability as dynamic features of social ecological systems is that these constructs are sometimes construed so broadly and generically that they result in rather diffuse, non-specific characterizations of people-environment relations. As such, they may fail to provide a useful basis for creating social and environmental interventions aimed at enhancing the overall quality and viability of a particular system. We address this challenge in a subsequent section by proposing certain analytic strategies for rendering social ecological analyses of resilience and sustainability more targeted and strategic, especially in terms of their capacity to guide the development of innovative, practical approaches for reducing contemporary threats to the stability of human-environment systems.

HISTORY: THE EMERGENCE OF SOCIAL ECOLOGY AS A CONCEPTUAL FRAMEWORK FOR UNDERSTANDING HUMAN-ENVIRONMENT TRANSACTIONS

The term, *ecology*, refers to the study of the interrelations between organisms and their environments. Ecological analyses of organism-environment relations originated among evolutionary biologists engaged in naturalistic observations of biomes—i.e., geographically bounded areas populated by both animal and plant species. These scholars (e.g., Darwin 1859/1964, Haeckel and Lankaster 1876, Clements 1905) were particularly interested in elucidating the processes of adaptation and natural selection by which the biotic components of a biome (i.e., resident plant and animal species) achieve dynamic equilibrium with its abiotic elements (e.g., climate, hydration, geologic conditions).

The conceptual and methodological tools developed by bioecologists during the 19th Century (especially naturalistic, longitudinal observations of plant and animal habitats highlighting homeostatic processes of adaptation) were later applied to the study of human communities, or ecosystems, by a group of sociologists at the University of Chicago during the 1920s and 30s. This group came to be known as the *Chicago School of Human Ecology* (Park et al. 1925) and was broadened to include like-minded sociologists based at other universities (e.g., Hawley 1950). The Chicago School combined the bioecologists' emphasis on adaptation processes with macro economic theories of urban development (e.g., Haig's (1926) theory of *highest and best use* of land and Christaller's (1933) *central place theory*) to explain the spatial distribution of financial resources, behavioral disorders, and health problems observed among sub-groups of Chicago's population residing in different zones of the metropolitan region.

However, the relationships between material and social dimensions of urban communities, as construed by the Chicago School human ecologists, emphasized the unidirectional influence of material conditions on social phenomena, rather than the reciprocal transactions among them. An additional limitation of the Chicago School's "concentric zone" theory of human ecology is that it over-emphasized biological and economic facets of human ecosystems while neglecting the sociopolitical, symbolic, legal, philosophical, ethical, and environmental design facets of human communities (cf., Michelson 1970). In his landmark article on "Sentiment and symbolism as ecological variables", Firey (1945) contended that environmental elements of human ecosystems convey symbolic as well as material meanings that often exist independently from or in contrast to their economic and locational values. Similarly, Alihan (1938) had published an earlier critique of the Chicago School calling for the establishment of a more integrative interdisciplinary conceptualization of human communities that combined the concerns of bioecology and economics with those of law, ethics, anthropology, urban planning, psychology, sociology and a variety of other fields.

Alihan and systems theorists such as Emery and Trist (1972) writing after her, referred to this broader conceptualization and study of human-environment relations as social ecology. This more integrative vision of human ecosystems gradually took institutional form, as university-based training programs in Social Ecology were established at the University of California, Irvine and the University of Vermont (Binder 1972, Bookchin 2005). Bronfenbrenner's (1979, 1992) ecology of human development research conducted at Cornell University similarly reflected a broad-gauged conception of human-environment transactions spanning micro, meso, and macro-societal levels of analysis. Bronfenbrenner's work has helped shape the research directions and conceptual orientation of Cornell's College of Human Ecology. Other institutional initiatives have since taken root –e.g., the Social Ecology Program at Yale University's School of Forestry and Environmental Studies, and the Program in Social Ecology at the University of Western Sydney. In contemporary scholarship, social ecology generally refers to the study of communities from a broad, interdisciplinary perspective that encompasses bioecological and macro-economic concerns, but gives greater attention to the social, psychological, institutional, and cultural contexts of people-environment relations than did earlier human ecology research (Michelson 1970, Moos 1979, Stokols 1996, Redman 1999, Stokols et al. 2003, Ostrom 2009, Peterson 2010).

Thus, the emergent notion of Social Ecology was founded on a realization that there were inherent limitations in the initial attempt to translate social phenomena wholly into material/ecological terms, an insight stemming in part from early phenomenological work on the difference between natural and semiotic worlds (cf., Husserl 1900). Phenomena in the symbolic/semiotic plane may behave according to altogether different logics from those in the material plane. Take, for example, the notion of natural selection in the material plane which, when translated into notions of "social Darwinism" violate deep ethical norms and run counter to contemporary concerns about environmental justice (cf., Bullard 2005). Or consider how increasing organizational structuring goes against a principle of entropy maximization. In fact, there is increasing interest in studying how ecological and other forms of governance are influenced not only by material or economic rules and logics, but also by complex narratives (Lejano and Stokols 2010, Lejano et al. 2012). In social ecological systems, what Aristotle referred to as formal causes are as important as the efficient causes of phenomena (Altman and Rogoff 1987).

For these reasons, the social ecological paradigm begins with an appreciation of how persons, groups, and other actors subsist in and through transactional relationships among interacting natural and semiotic systems. Rather than view the material and semiotic as independent or even dialectically opposed systems, the social ecological perspective enables us to view a continuous exchange between these systems. These exchanges, which we call transactions, are bidirectional and mutually influencing.

CORE PRINCIPLES OF SOCIAL ECOLOGY

Our conceptualization of resilience in human-environment systems incorporates certain core principles or themes emphasized in contemporary social ecological research:

First, social ecology highlights the *multidimensional structure of human environments*. Environmental settings can be characterized in terms of their physical and social components; natural and built (or designed) features; objective (material, observable) as well as subjective (perceived, semiotic) qualities; and their scale or immediacy to individuals and groups (proximal vs. distal). Moreover, the participants in environments include individuals, small groups, and organizations

that also comprise larger communities and populations.

Second, social ecological analyses incorporate *multiple levels of analysis* and diverse methodologies for assessing the resilience and healthfulness of settings and the well-being of individuals and groups. This contextual, multi-level perspective construes human environments as complex systems in which local settings and organizations are nested within more complex and remote regions. Thus, efforts to understand and enhance the resilience of particular human-environment systems must take into account the interdependencies that exist among immediate and more distant environments (cf., Stokols et al. 2009).

Third, social ecology draws upon key concepts and assumptions derived from systems theory, such as *interdependence*, *homeostasis*, *negative feedback*, *and deviation amplification*, to understand the interrelations among people and their surroundings (Maruyama 1963, Katz and Kahn 1966, Emery 1969). Systems analyses suggest that the resilience of particular settings and the well-being of their participants are jointly influenced by multiple facets of the physical environment (e.g., geography, architecture, technology) and the social environment (e.g., culture, ethics, economics, politics, law). The resilience and healthfulness of these settings is also influenced by the attributes of individual members including their genetic heritage, cognition, and behavior. From the vantage point of ecological systems theory, efforts to promote organizational or community resilience should be based on an understanding of the dynamic reciprocal transactions that occur among diverse environmental and personal factors, rather than on analyses that focus more narrowly on specific environmental, biological, or behavioral causal factors. These cycles of mutual influence are relationships that are both structuring and agentic, wherein people not only are acted upon by their environment or merely reproduce larger socio-cultural constructs, but plan-fully act to modify these as well (Giddens 1984).

Fourth, social ecological analyses of human-environment systems emphasize a *transdisciplinary action research* orientation in which diverse knowledge cultures or epistemologies (e.g., academic-disciplinary, professional-practitioner, lay citizen perspectives) are brought together for purposes of better understanding and ultimately improving the resilience and sustainability of people-environment systems (cf., Stokols 2006, Brown 2010).

How do we study phenomena that occur in both material and symbolic worlds? Not by subsuming one under the other but, rather, by studying the dialectic (i.e., the exchange, relationship, or transaction) that occurs among them. Thus, social ecology emphasizes processes involving transactions among multiple and ontologically diverse assets, resources and actors. Close attention is paid to the interchangeability of what Bourdieu referred to as multiple forms of capital (Bourdieu 1977, 1986). In Bourdieu's framework, the term capital refers to any resource or asset that social actors can employ to further their goals. Social capital, for example, can be understood as a personal asset residing in an individual's network of supportive relationships (Bourdieu 1986). (Coleman 1988) draws a distinction between human and social capital: "...human capital is created by changes in persons that bring about skills and capabilities that make them able to act in new ways. Social capital, however, comes about through changes in the relations among persons that facilitate action''. Putnam (2000), on the other hand, emphasizes the community benefits of social capital, which he defines as ''features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit''.

In Table 1, we illustrate different forms of assets that society can capitalize on in meeting its goals (cf., Stokols et al. 2003). These assets are grouped under two categories, material and human resources. The former includes *economic capital*, or material goods that facilitate the creation of new products and financial growth (cf.,

Marx 1930); *natural capital* or those resources produced through nature-based processes (e.g., geochemical, geothermal), as distinct from *human-made environmental capital* such as buildings, vehicles, tools and other products created by people (cf., Costanza et al. 1997, Daily and Ehrlich 1999, Hawken et al. 1999); and *technological capital*, an important sub-category of human-made environmental capital exemplified by telephone systems, computing and mobile communications equipment, and fiber optic technology (cf., Castells 1996). The second category of societal assets shown in Table 1 includes *human capital* created through changes in persons (e.g., educational experiences) that equip them with new skills and capabilities that enable them to act in new ways (Coleman 1988); social capital, or changes in the relationships among persons that facilitate their coordinated action for mutual benefit (Bourdieu 1986, Putnam 2000); and finally, *moral capital*, or the investment of personal and collective resources toward the cultivation of virtue and justice (cf., Rosenblum 1998, Berkowitz 1999, Miller 1999, Stokols et al. 2003).

Moral capital is a crucially important, yet often overlooked, societal asset that, like access to knowledge and other forms of human capital, can be used to ensure that community resources such as natural, social, and technological capital, are used wisely for the benefit of all citizens. Note that social capital does not necessarily pre-suppose the existence of moral capital. For instance, the strong bonds of brotherhood that often exist among members of violent gangs are typically cultivated and maintained at the expense non-members in the community who are victimized by their actions. Moral capital, on the other hand, speaks to collective norms that transcend intra-group social ties and inter-group differences. The moral capital of a community or society, for example, pertains to the broad collectivity of its constituent sub-groups, organizations, and institutions. The cultivation of moral capital depends not on the existence of strong social bonds among members of particular sub-groups in society, but rather on the ethical reconciliation of conflicting goals and interests among community sub-groups in ways that promote the long-term betterment of the collectivity as a whole.

Moral capital is an essential dimension or characteristic of a resilient society. A resilient community or society is ultimately fair, self-reflective, and self-critical in the ways that it addresses alternative points of view and differences among the members of its constituent subgroups. High levels of moral capital within a community or society would be reflected, for example, in the existence of widely shared, consensual guidelines for mobilizing and distributing community resources (e.g., public policies that ensure access to high-quality health services among all members of the population, and those that mitigate or prevent instances of environmental injustice (cf., Bullard and Johnson 2000, Stokols et al. 2003). Societies lacking widely-shared, ethical norms to guide the development and distribution of limited resources among their component groups are likely to be less resilient and effective in their responses to environmental perturbations and resource scarcities than those collectivities in which high levels of moral capital prevail.

In a social ecological framework, interchange among different forms of capital are understood as transactions: dynamic processes of exchange, mutual influence and adaptation between and across systems (e.g., social and physical environments). In this manner, Social Ecology focuses on exchange across scale (e.g., local-global), organizational boundaries (e.g., neighborhood and region), and knowledge bases (e.g., experiential and scientific knowledge). By being open to the everyday experience of subjects, the social ecological frame coheres well with action-research as a mode of participative-collaborative inquiry.

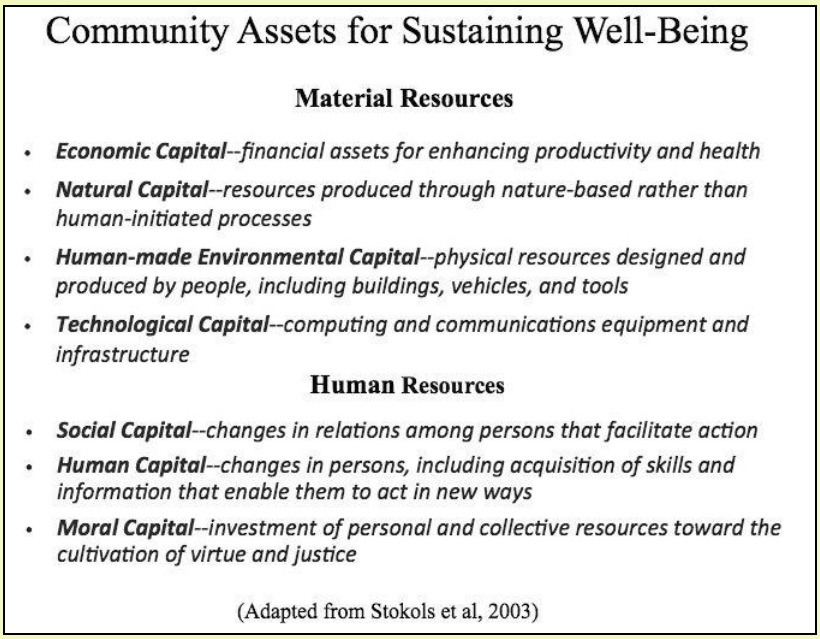

Table 1. Forms of Capital

The proposed multifaceted conceptualization of capitalized assets has direct relevance for resilience theory, which highlights transactions wherein decrements in one form of capital (e.g., contamination of water supply due to extreme weather events) are remedied or complemented by the mobilization of other forms of capital (e.g., social capital in terms of a network of emergency service providers, moral capital in the form of norms about sharing in times of need). On the other hand, obstacles to such transactions can characterize non-resilient systems (Gunderson and Folke 2011, Schoon et al. 2011). In the following sections, we illustrate how these transactional processes are analyzed, and how the configuration of such transactions can result in higher or lower levels of system resilience.

DYNAMIC FEATURES OF RESILIENT AND NON-RESILIENT SYSTEMS

The social ecological of resilience, proposed here, suggests new ways to understand resilience, while also being consistent with Walker et al.'s (2004) conceptualization. For example, one way to construe resilience from the vantage point of our own social ecological perspective would entail an explicitly transactional, process-oriented definition, as follows:

Human-environment systems are characterized by mutually overlapping transactions wherein humans adjust to (i.e., situationally constraining or promotive) influences of the environment on the achievement of social goals, and in turn, attempt to modify the environment in furtherance of these same goals. Resilient systems are those wherein both processes of adaptation and modification exist that positively and mutually support these goals for the overall betterment of the collectivity, as a whole.

In the context of people's reciprocal transactions with their environments, their goal-oriented behavior may follow the logics of material, biological, or economic advantage, but also can be constructed according to more complex narratives (Lejano et al. 2012). We also stress that such goal-oriented behavior need not follow the logics of material, biological, or

economic advantage exclusively, but rather can be constructed according to more complex narratives. Moreover, a transactional approach emphasizes the bidirectional nature of exchange between humans and their environments.

One strategy for representing the level of resilience in a system is to identify circumstances under which various kinds of people-environment transactions are mutually supportive (progressive) or mutually non-supportive (regressive) as depicted in Figure 1. As a basis for extending earlier ecological analyses of resilience, we introduce the idea that resilient transactions in human-environment systems depend on the effective and strategic mobilization of different kinds of material and human resources for purposes of achieving and sustaining desirable states of the system. It is through effective mobilization or capitalization of these community assets that higher levels of adaptability, resilience, and longer-term sustainability can be achieved (Stokols et al. 2003). Key categories of material and human resources or capital are as previously listed in Table 1. Figure 1 emphasizes the transactional notion of human-environment interactions, and one might even see it as a more process-focused interpretation of the concept of *panarchy* proposed Gunderson and Holling (2002).

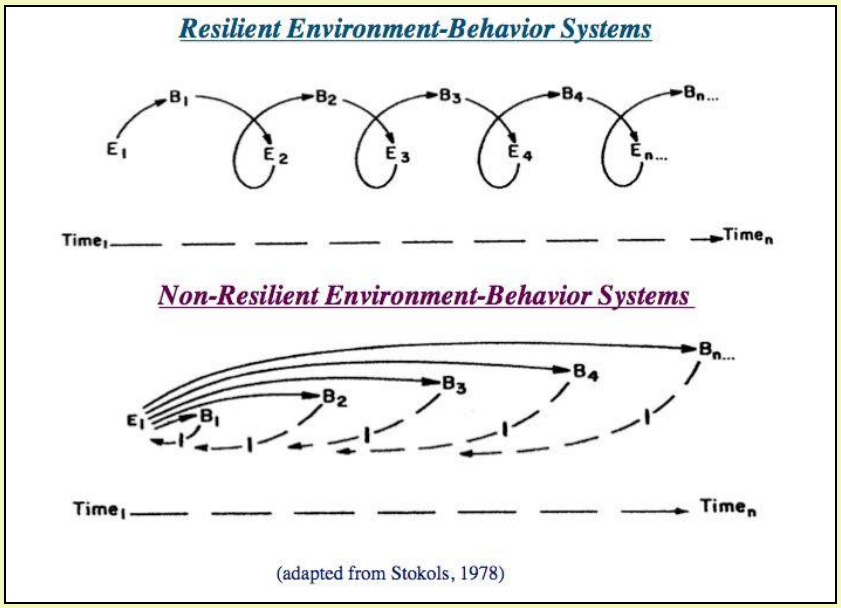

Figure 1 Schematic Representations of Human-Environment Transactions

In Figure 1, we see sequences of environment-behavior (E-B) transactions wherein changes in environment can induce a variety of behavioral, physiological, and sociocultural responses. In resilient systems, environmental changes in an ecosystem prompt its members to make various kinds of changes in their sociophysical environment that are intended to enhance the level of congruence or fit between themselves and their surroundings (cf., Michelson 1970, Stokols 1978). In turn, these environmental modifications evoke subsequent behavioral changes aimed at achieving even higher levels of human-environment fit. These reciprocal cycles of mutual influence between environments and the behavior result in a pattern of

continually evolving and mutually adaptive transactions. This model also can apply to non-human organisms and objects as actors. This latter attribution of agency to nonhuman actors is quite possible in a social ecological analytic framework; it is given great importance in some conceptual frameworks such as Latour's (2005) actor-network theory.

In contrast, less-resilient systems are depicted in the lower half of Figure 1 in which physical or institutional environments are so rigidly constrained and unyielding that it becomes impossible for the actors in these systems to modify their surroundings in adaptive fashion. The inability to modify situational constraints in accord with personal or group goals is represented by the blocked, broken arrows leading from behavioral states at times 1-n toward the unyielding environmental conditions (E1). Thus, their behaviors remain captive to the dictates of a rigid environment, thereby precluding any mutually adaptive, reciprocal responses between environmental changes and corresponding human/agent behaviors. In the discussion below, we illustrate these two contrasting patterns of environment-behavior transactions.

Our analysis further assumes that *transactions involving certain kinds of capital, as compared to others, may exert greater leverage toward either diminishing or bolstering the resilience of a system. Accordingly, it becomes essential to identify high-leverage points of intervention within complex, multi-level systems, as a basis for strengthening the resilience of an individual, organization, community, or society.* By so doing, we are able to extend previous and less targeted social ecological models by focusing on the points of highest leverage in a system for enhancing its resilience; and perhaps, by also offering criteria or guidelines for characterizing the relative leverage or impact value associated with various system components.

The social ecological paradigm encompasses, as part of its focus on transaction, the ongoing exchanges among people and environments that occur across varying times and scales. It is important to consider both the temporal and spatial scale of the system under study. The temporal dimension is essential for understanding the level of resilience of a system. In some cases, a system may demonstrate short-term stability. However, the ways in which the system maintains equilibrium in within a particular time frame may actually render the resilience of the system more fragile in the longer run. Of course, what actually constitutes "short-term" or "long-term" varies based on the particular system being studied. Thus, gauging the level of system resilience requires explicitly defining the time frame being considered, and considering whether higher levels of short-term resilience may actually result in lower levels of long-term resilience.

Similarly, defining the spatial scale of the system is crucial within the social ecological approach. In some instances, sub-components of the system may be more resilient than the larger whole. It may also be the case that the resilience of some systems requires the maintenance of only some sub-parts of the larger system. Conversely, in certain instances the resilience of smaller portions of the larger system can result in negative consequences for the entire system. In part, our notion of moral capital is meant to capture such circumstances. Nonetheless, it is useful to explicitly consider the spatial scale of the system under study.

These considerations also underscore the point that simultaneously considering the temporal and spatial scales is essential for understanding system resilience. The resilience of certain portions of the system, within certain time periods, may well differ from the resilience of the entire system over more extended temporal periods.

Example A:
Nonresilient Political Ecologies

As an illustration of the points discussed above, the current financial recession and debt-ceiling debates can be viewed in terms of the dynamic interplay

among various kinds of resources, including financial capital (currency values, stock prices, interest rates, GDP, national debt), ecological capital (e.g., protection and preservation of natural resources through environmental conservation strategies), technological capital (e.g., development of clean energy technologies; high volume purchases or sell-offs of corporate stocks that are triggered by rather rigid computer algorithms), social and human capital (increasing rates of income-inequality and uneven access to educational and employment resources in US society), human made (vs. natural) environmental capital (e.g., establishment of an infrastructure development program in the US to reduce unemployment), and finally moral capital or lack thereof (e.g., the unwillingness among many members of Congress to compromise in the interests of achieving balanced solutions to the US debt problem and their corresponding zeal to crash the system by forcing the US to default on its debt).

The example of the recent US debt ceiling debates in Washington exemplify what Schoon, Fabricius, Anderies, and Nelson (2011) refer to as *robustness-vulnerability tradeoffs* and potentially devastating *lock-in traps* that often arise within non-resilient systems. It seems plausible to suggest that the disadvantageous tradeoffs favoring greater vulnerability (over robustness) and heightened potential for creating inescapable lock-in traps are occurring within the US economic systems, and more broadly within the global economy, not because the US government lacks the financial capital to invest in infrastructure development (environmental capital) or novel green energy technologies (technological and ecological capital), but rather because its politicians lack sufficient consensus and fortitude to take collective action (e.g., strategic investments of economic capital as an adjunct to cost-cutting measures) that would promote job growth, lower the national debt over the long run, while also reducing income inequality and strengthening social capital.

In this example, *the greatest leverage for enhancing the resilience of the US and global economy would be achieved by mobilizing human resources such as social and moral capital*, such that opposing political factions are better able to accommodate to the concerns and needs of others they view as outsiders. Thus, the economic, environmental, technological, human, and social capital in our national system could be substantially enlarged through focused efforts to strengthen social and moral capital. A potential strategy for increasing coordinated action among factions that currently oppose each other may be to create situations or scenarios that raise the salience of shared, superordinate goals (Sherif 1958).

However, the United States' present financial system is characterized by perverse feedback mechanisms that lead to greater volatility (and, hence, decreased resilience). Consider how digital technologies, rather than compensating for decrements in financial capital, compound the problem. By enabling more rapid and larger-volume transactions, digital technology exacerbates the upswings and downswings in stock prices (Sweet 2011, August 12). In 2008, these automated (and in many respects, *mindless*) processes helped push the stock market beyond a tipping point, from which it has taken almost three years to recover. Consider also recent political responses to these economic crises by members of the US Congress, which rather than move toward a concerted effort at jobs creation or stimulus, has instead focused on fueling an ideological divide that has stalled efforts to move beyond issues like the debt ceiling and deficit reduction, and on toward the development of effective fiscal stimulus strategies

A social ecological perspective on resilience, as reflected in Figure 1, would entail analyzing the different sequences of system change (E_1), the suite of behavioral responses (B_1, B_2, etc.), and the resulting processes of system modification. This process-based understanding of resilience enables us to view these transactions as

either lending to reduced volatility or exacerbating it. The notion of interlocking forms of capital also allows us to view whether different forms of capital counteract decrements in the resource or economic base. In the above case, the analysis might find perverse effects, where decrements in financial capital lead to a degradation of social and moral capital (as evidenced in budgetary and ideological gridlock)—exemplifying what Maruyama (1963) referred to as deviation amplifying processes in systems.

Example B: Resilient Adaptations to Environmental Stress

Let us describe, in more concrete terms, how a social ecological framework can guide environmental research. Shown below are two figures: Figure 2a, which is a map depicting a classic risk analysis of air toxics emissions from a landfill in Southern California. Figure 2b, on the other hand, is a mapping of certain measures of anxiety or salience of risk, revealed in cognitive mapping exercises and ethnographic interviews in the same community (Lejano and Stokols 2010). This research combines and juxtaposes different dimensions--on the left, the natural/material, and on the right, the dimension of meaning.

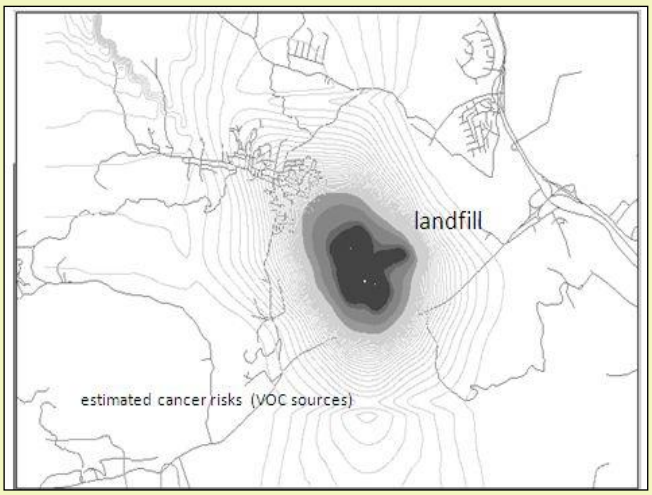

Figure 2a. Risk Contour Map

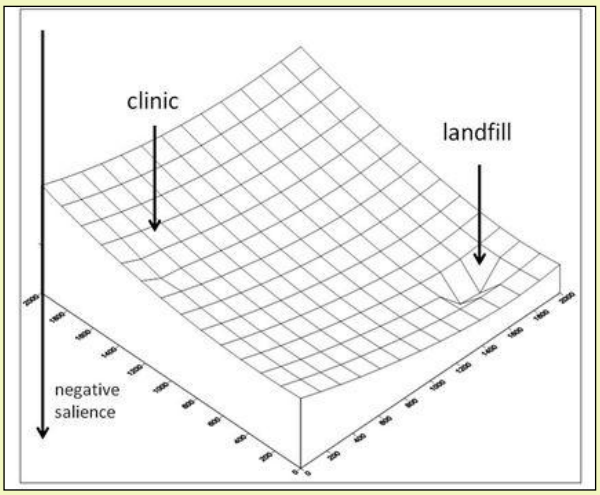

Figure 2b. Risk Perception Map

Analysis has not only to cross scales but, in this case, traverse dimensions. In Figure 2, the two dimensions or systems being analyzed consist of experiential and scientific knowledge systems. To do this, we study transactions between the two, not in traditional systems terms (as systems of objects, state parameters, and governing equations) since we cannot characterize the "equations" found in the dimension of meaning. Instead, we understand transactions as practice-knowledge complexes (Berkes 2008). First, we examine how Figure 2a and 2b are related, and how community experience translates into the perception map. Next, we observe the detailed everyday actions that must change if the community is to respond to the perceptions of risk experienced in Figure 2b. These actions, which cannot be modeled since they emerge from countless possibilities and complex logics, are seen at different scales of action--at the personal, as parents reroute their childrens' daily round away from the risky areas; at the local, as community members do door-to-door surveys of health; at the agency level, as

these residents picket the County Supervisors' office (dressing up as skeletons during *El Dia del Muerte*); and at the global level, as the community group begins interfacing with environmental justice groups worldwide.

We would then study the transactions that proceed in the other direction, influencing the natural environment (e.g., Figure 2a). This involves tracing how the suite of responses lead to counter-responses at different levels: the regulator adjusting air quality monitoring schedules; the landfill operator increasing watering at the dumpsite (minimizing re-suspension of particulates); changes in exposure as residents' daily round adjust to the perceived risks. Over time, these processes effect changes in the risks mapped in Figure 2a. This change then spurs additional responses from the community and other policy actors as they contemplate further actions that build on earlier successes.

Alternatively, the situation may be characterized by institutional impedance, where, as in the non-resilient system depicted in Figure 1, the residents find their protests, institutional appeals, and self-monitoring to be hindered by a lack of legal precedence for instituting changes in landfill operation. For example, the measured risks may be found to fall below regulatory thresholds, or the landfill operator exerts lobbying pressure to forestall action at the regional level.

Resilience, in social ecological terms, is seen in this example as the generation of social capital in response to decrements in physical capital, the latter being the adverse air quality experienced on a daily basis by community residents. The focus of our analysis, thus, is on processes and the transactions or exchanges between the two forms of capital, physical and social. Because this type of research combines different knowledge bases, it affords participation of the affected residents themselves, not just in cognitive mapping exercises but also by voicing their experiences of risk and empowerment.

CONCLUSIONS

To summarize, a social ecological frame of analysis improves our understanding of the resilience of human-environment systems, and of complex multi-scale, multi-temporal environmental phenomena in multiple ways:

1. By focusing on transactions, especially between the dimensions of physical/natural systems and systems of meaning, we pay close attention to exchange (i.e., response and counter-response) between these systems, and between different sub-systems (e.g., community and regional government).
2. By understanding transaction as a complex of action and knowledge, we remain open to using approaches from action-research and participatory-collaborative learning in transdisciplinary fashion.
3. By so doing, we are able to combine scientific, physical-systems knowledge with symbolic and experiential knowledge.
4. Finally, rather than subsuming socio-cultural systems under the frameworks and logics of natural systems research, we remain open to the complex logics of the socio-cultural.

In this type of inquiry, human-environment transactions are construed not as static notions of fit nor describable by equally static (and determinate) governing equations, but as complex and dynamic processes of adaptation and counter-adaptation.

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