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Mutual vulnerability, mutual dependence The reflexive relation between human society and the environment.

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Abstract

Human society affects environmental change but is also vulnerable to these changes. This relation has generated a number of theories that either focus on how we affect the environment or how the environment affects us. Few theories explicitly focus on the interaction. This paper will establish the range of data required to give an assessment of how likely an ecosystem is to change (which we label *environmental sensitivity*) and the ability of communities to adapt (*social resilience*). These findings allow us to generate a new method for assessing the reflexive relation between society and the environment.

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1. Introduction—the reflexive relation between nature and human society

Humans create environmental degradation. The impacts of human activity reach all aspects of the planetary ecosystem, but are most closely associated with air, water, and soil degradation (Thomas and Middleton, 1997; Lambin et al., 2001). For example, the Intergovernmental Panel on Climate Change (2001b) recognizes that human activity is a significant driver behind climate change and Walker (1997) argues that human activity plays a significant role in affecting the planet's shoreline ecosystems.

The environment also sets limits on the possibilities of human activity. Historical evidence shows that Vikings settled Greenland during a warm period but subsequently abandoned these communities as the area cooled. Modern day society is similarly constrained by the environment. Despite tremendous advances in agricultural science, climate and weather are the most important variables in food production (Rosenzweig et al., 2001). There is also a growing understanding that environmental factors—even those as simple as the long-range transfer of dust particles—may affect human health in ways we do not understand (Griffin et al., 2001). Hence, the environment has always been, and will always be, a powerful constraint on human society (Deudney, 1999).

These are direct cause and effect relations that do not require debate. Other problems are more challenging. Indirect causality, complex causal chains that bring unpredictable surprises, and the reflexive nature of the environment and society require creative analysis and scholarship. For example, human management decisions may lead to changes in the environment, which in turn can impact upon the human population in new and often unforeseen ways. The result of these impacts may be new management decisions that feed a further cycle of environmental reactions and human responses. Examples include human-induced climate change that may lead to a rise in sea levels. This threat has forced scholars to question the future security of such small island nations as Tuvalu (Barnett and Adger, 2001). Forest fires in Indonesia, lit to clear land for agriculture and grazing in 1997, caused a cloud of smoke to cover much of South East Asia. This forced 50,000 people in neighbouring Malaysia to seek medical attention. Global climate models link industrial activity in Canada and Australia, which create clouds of aerosols, to the African droughts of the 1980s (Nowak, 2002). Past attempts to understand and analyze this interaction have not been successful. Malthus' famous hypothesis that a lack of agricultural productivity and population growth would lead to starvation, disease, and death was

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wrong (Malthus, 1976). Recent examples of doom-laden analyses that have failed to come to pass include work done by the Club of Rome in the 1970s (Meadows and Club of Rome, 1974; Pestel and Club of Rome, 1989). This has led some to suggest that human resourcefulness will inevitably find solutions to environmental challenges (Simon, 1981; Boserup, 1981).

Perhaps because of these factors, the environment continues to occupy a place of low priority for a majority of nations. In countries where improving environmental management has become a priority, much work has been focused on preserving ecosystem cohesion and structure. For instance, ecosystem management (EM) is an approach to natural resource stewardship that emphasizes ecological goals and recognizes the sensitivity of the environment to human actions. However, a necessary component of EM is the need to acknowledge human activity as an active component of the ecosystem, so resource managers must find compromises between human needs and environmental integrity (Grumbine, 1994, 1997).

This compromise emphasizes three complexities in the relation between human society and the environment. First, the nature of the environmental response may be unforeseen and may take years to be felt. Second, the population that impacts the environment may not be the same population that is affected by the environmental problem. Finally, different communities will have different abilities to adapt to changes. Hence, we must move beyond simple cause-and-consequence to understand how humans and the environment interact. If those that make environmental policy fail to understand the reflexive nature of this relation, it is possible (and perhaps inevitable) that human populations will be threatened by negative ecological changes caused by unintended but inappropriate management of our natural resources. This builds on early papers in the journal *Global Environmental Change* and on the 1996 IPCC report *Climate Change in 1995* (Watson et al., 1996).

2. The problem in context: contested frameworks

Scientists have struggled to determine an analytic framework to articulate, describe and understand the reflexive relation between humans and the environment (Kasperson et al., 2001; Smith, 2001). For example, in the 1990s, scholars worked on models to illustrate the role of environmental scarcity in generating conflict (Homer-Dixon, 1995, 1999). The Rwandan genocide was identified as an event that can be traced back to both environmental scarcity and population pressure (Patterson, 1995). Some, however, argue that scarce and degraded agricultural land was only one of many factors at work, which included political problems, ethnic tensions, and unemployment (Uvin, 1996). Critics also suggest that linking the environment to conflict draws attention away from the importance of poverty in generating social unrest (Dalby, 1999).

One of the challenges of linking environmental variables to individual or societal security is the implication that environmental issues should be given the same priority as national security. This is controversial, as, in one author's opinion, it is "…analytically misleading to think of environmental degradation as a national security threat because … [national security] has little in common with either environmental problems or solutions…" (Deudney, 1999, pp. 189–190). Therefore, recent studies have moved away from a narrow focus on conflict, concluding that it is wrong to suppose that a simple deterministic link exists between human-caused disturbances, environmental degradation, and specific societal responses (Kasperson and Kasperson, 2001). Scholars now view the interaction between the environment and human society as one constraint that influences how livelihoods in a region may be vulnerable to disruption and how different social systems will respond to this vulnerability (Ohlsson, 2000). This approach is interesting because it allows for multiple interpretations of a given situation. For example, declining social resources could increase the vulnerability of a population to environmental disturbances even if there is no change in the surrounding ecology. Similarly, a changing environment may in turn increase the vulnerability of a local population to an acute climatic event, such as a flood or storm, even if the social resources of that population remain the same. To move forward, and help policy makers and scholars understand these complexities, we need to develop tools that link environmental and human variables, so it is possible to evaluate trade-offs between different policy options.

A wide variety of tools already exist that attempt to describe the human–environment relation in ways that are meaningful to policymakers. Some of these tools measure the impact of industrial society on resource availability, such as the Genuine Progress Indicator (Anon, 2002; Daly and Cobb, 1989) and the Total Material Requirement Index (World Resources Institute, 1997). Other tools attempt to provide guidance that will ensure long-term access to natural resources, such as the Living Planet Index (Loh, 2000) and the Environmental Sustainability Index (Global Leaders of Tomorrow Environment Task Force, 2002). As these tools are generally created with a goal of informing decision-makers on certain issues, they naturally focus on a limited portion of the human–environment equation and do not always succeed in capturing the interactive dynamic of the relation. At the same time, excellent bodies of information are collected that are intended to offer policymakers a basis for sound governance decisions. The Land Use Cover Change project and the Centre for International Earth Science Information Network are examples of ventures that collect social and environmental variables and organize them in ways that can promote wise use of natural resources. Prescott-Allen (2001) uses similar datasets to conduct holistic well-being assessments of populations.

One common feature of the existing tools and datasets is that, for the most part, they focus on national level analyses, which disguise intra-country variability and use artificial or social boundaries to measure environmental factors. There is a pressing need to adapt these tools to understand human vulnerabilities to environmental change across a range of scales, and to improve the measurement of environmental variables by incorporating existing knowledge of ecosystem boundaries and environmental pathways.

This is particularly important in light of climate change models, which predict an increase in the frequency of extreme weather events (Intergovernmental Panel on Climate Change, 2001a). It is important to anticipate those populations that will be vulnerable to environmental change so that appropriate policies can be developed before crises emerge. Part of the challenge is the fact that we cannot adequately predict the nature or scope of the changes that may be faced in the future, and we have little insight into how communities will be able to adapt to these changes (Smith, 1997). In order to meet this challenge, social and environmental data must be fused within a single analytic framework that reflects our understanding of the social causes of vulnerability and integrates social causes and reactions into the analysis of environmental problems ([1]Adger, 1999; Smith, 2001). This framework must guide researchers and policy makers to correctly identify both environmental and social threats to individuals' livelihoods.

3. Adaptive frameworks: environmental sensitivity and social resilience

Human society has developed culture and institutions that help us adapt to environmental changes. Therefore, understanding the physical nature of global environmental change is not in itself sufficient to help us develop solutions to problems like climate change (von Storch and Stehr, 1997). Environmental problems involve multiple, interacting causes (Taylor and Buttel, 1992).

The challenge is to combine social and environmental data in meaningful ways, which nevertheless respect the differences between these types of systems. We begin with Holling's (2001) model of how ecosystems adapt (or fail to adapt) to shocks or sudden perturbations based on cycles of resource accumulation and release. This theory suggests that ecosystems, including human-influenced ecosystems, are complex systems that respond unpredictably when conditions change. A "complex system" has a number of distinctive characteristics that include what are known as "emergent properties", "strange attractors", "non-linear effects", "threshold effects" and "bifurcations" (Kauffman, 1995; Bar-Yam, 1992). Because of these characteristics, complex systems respond in unpredictable ways to stimuli and remote influences can have a major effect on the system. Complex systems can also go through relatively long periods of stability and then "switch" into a period of perturbations and chaos (Gleick, 1987). Holling's key insight is that inside this complexity are generalizable traits and that it is possible to characterize complex systems using a small number of variables (Holling, 1986, 2001).

Therefore, we propose that our framework combine multi-scalar social and environmental data by using two key variables: (1) *Environmental sensitivity*, which describes the relative likelihood of damage occurring due to an attack by pests, exposure to toxic materials, or adverse environmental conditions (Holling, 1986): and (2) *Social resilience*, which focuses on whether a society will be able to respond to environmental changes. This introduces a human element into a classic ecological definition of resilience, which is the ability of a system to maintain its characteristics when disturbed (Holling, 1986). Smithers and Smit (1997) argue that this is understudied, and most models assume that communities either will or will not be able to adapt to change, with little understanding of "…how, when why and under what conditions adaptations actually occur in economic and social systems" (Smithers and Smit, 1997, p. 129). Therefore, to measure social resilience, scientists should ascertain if societies have the "ingenuity" or resources (broadly defined to include material and cultural factors) to meet the challenges of the future (Homer-Dixon, 2000).

Together, environmental sensitivity and social resilience describe the balance that must be addressed between social and ecological resources in order to understand the human–environment relation (Alcamo and Endejan, 1999; Alcamo, 2002).

3.1. Variable #1: environmental sensitivity

The sensitivity of the environment to changes, shocks and stresses is an important factor in many environmental problems. Deforested ecosystems, ecosystems with low soil-bound organic matter, or areas with steep slopes may have reduced water-holding capacity and be more vulnerable to drought or erosion. For example, in the late 19th and early 20th centuries, the government of Ontario, Canada, offered incentives to clear land and establish farms north of Toronto. This region, called the Oak Ridge Moraine, is made up of glacial till, a mixture of clay, silt, sand, and stone. This soil is erosion-prone once the vegetation is removed, and the area only supported agriculture for a few decades. With the original forest cover removed, and the soil organic matter exhausted due to agriculture, the ecosystem's natural buffers against drought were gone. Massive erosion ensued during the drought of the 1930s, constituting Ontario's dust bowl. Snowploughs were used to clear eroded sand from highways and roads in what is now a suburb north of Toronto (Roots et al., 1999).

To measure environmental sensitivity, data rely on quantitative biophysical information. We propose to build on the 'regions at risk' hypothesis brought forward by Kasperson et al. (1995). This theory states that different ecological regions are inherently more vulnerable to environmental change than others. In order to identify these regions, it is important to gather basic biophysical data for the specific areas examined. This information should include ground and surface water flows, slope and soil morphology and land cover data. When inputted onto a geographic information system (GIS), this baseline environmental data will help illustrate whether a region has enough ecological adaptability to allow it to adapt to changing environmental conditions.

Using the GIS we can trace the pathways that environmental disturbances follow as they move through a landscape. The study of pathways has evolved from the need to identify the environmental fate of human-made chemicals (Mackay, 1991), a task based upon a description of the media through which these chemicals may pass. Pathways can be described by three factors: the transport medium (atmosphere, water, soil, terrestrial or aquatic biomass, aerosols, suspended sediment, and bottom sediment), the mobility of the medium, and the connectivity of the medium to local, regional, and global systems.

The pathway approach is an effective way of dealing with the issue of spatial scale for ecological data. For many environmental problems, the appropriate unit of analysis will be a watershed, a groundwater source, or a small island. These units are defined by the presence of transport mechanisms that have access to relatively short and mobile pathways, through which the immediate impacts of an environmental disturbance can be transmitted. For example, the loss of forest cover within a river valley results in local problems such as erosion and the loss of vegetation. These problems, however, are contained within that watershed system, as the connectivity of such a system is restricted by the river's path. Such an event may have impacts that could be immediately transmitted by the river itself, in the form of flooding due to increased run-off and associated increases in sedimentation. This would also represent a loss of terrestrial biota and could change the conditions of the aquatic system, perhaps making it less hospitable to aquatic biota. Finally, it would likely lead to local erosion and loss of soil, changing the overall structure of the valley and leading to a loss of potential for new biota to establish itself in the short term.

Larger landscape units, such as ecotype or drainage basin, will be appropriate to capture long-term chronic environmental changes. The important differences between the regional and local level environmental units are that changes at the regional level occur at a more gradual rate, tend to be the cumulative result of multiple disturbances rather than the result of a single event, and are transmitted and felt over a much wider area than localized changes. In a watershed example, a localized disturbance may lead to a general loss in the hydrological capacity of the entire river basin. This might translate into changes in riparian characteristics, reduced habitat, and lead to the loss of entire species.

Some pathways, in particular the atmosphere and the oceans, allow for the transmission of environmental impacts to the entire global ecosystem. Of the two, the atmosphere is the most mobile, which is recognized by the Kyoto Protocol's emphasis on greenhouse gas emissions.

When a specific population is analyzed, the environmental pathways framework laid out here would mean that each transport mechanism present in the local environment must be analyzed. The ability of the local population to affect the environment through each transport mechanism must be measured, as well as the ability of the environment to affect the local population. Hence, using pathways is an appropriate way of characterizing complex environmental factors in a unified framework.

3.2. Variable #2: social resilience

To understand whether environmental change will impact communities, it is necessary to include with our ecological assessment an evaluation of how communities adapt to change. The academic literature on this subject is dominated by social scientists who propose theories of social resilience (Carpenter et al., 2001; Berkes and Folke, 1998) and of social capital (Boggs, 2001; Putnam, 2000). Carpenter et al. (2001) define social resilience as "the magnitude of a disturbance that can be tolerated before a socioecological systems moves to a different region… (Carpenter et al. 2001, p. 745). Berkes and Folke (1998) define it as the capacity of a system to absorb disturbances. Boggs (2001) defines social capital as "…networks of interaction among individuals that imbue human life with qualities needed for community, collective action, and democratic participation… (Boggs, 2001, p. 281). Berkes and Folke (1998, p. 417) present four guiding principles that help promote social resilience in resource dependent communities. These principles act as social mechanisms to help communities develop management structures that: (1) "flow with nature," (2) enable the development and use of local ecological knowledge to understand local ecosystems, (3) promote self-organization and institutional learning, and (4) develop values consistent with resilient and sustainable social-ecological systems. The IPCC has built on this literature and recommends that a broad range of categories should be used to determine whether a community would be vulnerable to climate change (as quoted in Yohe and Tol, 2002):

1. The range of available technological options for adaptation.
2. The availability of resources and their distribution across the population.
3. The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed.
4. The stock of human capital including education and personal security.
5. The stock of social capital including the definition of property rights.
6. The system's access to risk spreading processes.
7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers themselves.
8. The public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

The problem is that in this list, the IPCC proposes that everything social, economic, and political must be considered. This is neither possible nor useful in building explanatory models and we must find a middle ground between the overly simplistic, and the hopelessly complex. This echoes an on-going debate in human geography, where scholars, reacting against the notion that the environment determines human society, have embraced increasingly complex models to help explain the relation between the two (Muscara, 2000). Nevertheless, while rejecting determinism many human geographers still, pursue a "…quest for general and systemic principles in human geography" in order to develop robust, yet not overly complex models (Muscara, 2000, p. 286).

A second challenge with social data is determining the best scale at which to collect and analyze data. As social data are (at best) collected using household data, it is inevitable that a researcher or policy maker will use aggregate data (Cash and Moser, 2000). Empirical studies illustrate the problems with this approach. Work done in Africa, for example, shows that an increase in female income can elevate the household's food, health, and education budgets, and can greatly improve the chances for child survival, whereas similar increases in male income do not have the same results (Haddad et al., 1997). This problem is compounded by the fact that in most situations in rural Africa, household incomes are not generally pooled (Keopman, 1997). For this reason, it is important to identify the characteristics of local households in selecting indicators for the social resilience variable. Once the local context is understood, then more standard measures such as education levels, the presence or absence of marketable skills, and geographic and social access to marketplaces may be useful indicators to describe social adaptability to environmental change. Working at the household level maintains the focus on local issues of security or vulnerability. By incorporating the full range of these measures as indicators that support social resilience, it is anticipated that the second and final component of the reflexive nature of the human–environment relation can be captured.

To address the question of scale and find a middle ground between too complex and too simple models, we can draw from the social sciences, and specifically the study of food security, where it is common to use the local social, economic and political context to determine which categories are important in explaining social phenomena. For example, to assess whether specific populations are vulnerable to famine, Watts and Bohle (1993) propose to analyze vulnerability, which they define as the outcome between environmental and socio-economic forces. Specifically, Watts and Bohle are interested in the types of shocks or stresses that communities are exposed to and the methods they employ to cope. To help do this, we can use Sen's theory of food 'entitlements.' Any failure to meet food requirements, be it social, economic, or environmental becomes an 'entitlement failure' and can occur anywhere between the producers and the consumer of food, which makes entitlements a function of both environmental and social variables (Sen, 1980). If local people are affluent, a different set of criteria will be used to evaluate vulnerability than if people are poor. Similarly, different indicators will need to be used in areas where there are serious problems of gender equity. Therefore, Watts and Bohle (1993) argue that food security must be addressed from many perspectives and from a number of different scales as, "…vulnerability is a multi-layered and multi-dimensional social space defined by political, social and institutional capacities…" (Watts and Bohle, 1993, p. 46). While this literature typically focuses on food production and distribution, the approach can be adapted to look at a wider variety of both social and environmental variables and can aid in assessing the impact that environmental change may have on human security.

For example, in a subsistence agricultural community, it would be necessary to trace networks of labour, materials and capital used by individual families as a crop is produced, distributed and consumed. By mapping these pathways through the biophysical landscape it will be possible to illustrate how agricultural practices interact with soil conditions, and whether or not communities are dependent on a food system that might be vulnerable to disruption stemming from bad land management. Using Sen's terminology, this would mean that consumers would switch from a direct (subsistence) entitlement to an indirect entitlement. Poverty, however, prevents those who lose access to food that they grow themselves from switching to indirect means of obtaining food (Sen, 1988).

Homer-Dixon (1995) uses a similar method called "process tracing" to construct webs or networks of causal relations that link social and environmental variables. This approach is uncommon in research on the environment, where scientists tend to separate dependent and independent variables and use statistical methods to assess correlation. An approach based on process tracing, ethnography, or entitlement theory allows a researcher to differentiate between different causes of vulnerability, for example, problems caused by extreme weather or chronic problems that may be a result of poor access to resources (Chisholm and Tyers, 1982). This involves a careful and rich study of a region, using methods such as "…establishing rapport, selecting informants, transcribing texts, taking genealogies, mapping fields, keeping a diary…" (Geertz, 1973, p. 6).

The Rwandan genocide provides an illustrative example of the interaction between social and environmental factors. The debate on the origins of the tragedy spans a huge spectrum. Some authors cite complex social and political issues such as the traditional ethnic rivalry, Rwanda's colonial history, the indifference of the international community, and use of propaganda by the majority Hutu government (African Rights, 1994; Off, 2001; Lemarchand, 1995, 2000). Other authors use Malthusian-like arguments to stress demographic and environmental pressures that led to high rural densities, declining agricultural yield, "environmental" refugees in Zaire, and a large class of landless peasants (Newbury, 1998).

Uvin (1996, 1998) and Newbury (1998) conclude that it necessary to combine social and environmental factors to develop a multi faceted explanation of the tragedy (Uvin, 1996, 1998). As the African country with the highest rural population density, and without any significant industry, Rwanda is extremely dependent on agriculture for both consumption and income. In years leading up to the genocide, population growth, government land policy, and migration further increased population density, which forced farmers to reduce fallow periods, a loss of soil productivity, and a loss of pasture land for cattle, the most important source of fertilizer (Newbury, 1998). These forces combined to result in a loss of food production from approximately 2000 to 1500 kilocalories/person/day (Uvin, 1996). This coincided with a decline in the international price for coffee, Rwanda's major export. A combination of declining income, and reduced food security, therefore, were characteristic of Rwanda in the years leading to the genocide. While these arguments in no way imply that there is a necessary causal relation between soil fertility and civil unrest, work done by scholars of the genocide illustrate that conflict emerged in a complex environment that included social, economic and environmental characteristics.

Gasana (2002), former Rwandan minister of defence, suggests that environmental scarcities (specifically, unequal access to arable land), contributed to ethnic and economic fault lines already present in that society, and that it is possible to map pathways of violence from environmentally degraded rural areas to urban areas including the capital. When overlaid against a biophysical map of the affected area, it is clear that violence began in areas where agricultural land was seriously degraded. This analysis creates a sort of "watershed" of violence that combines the local context, national political and economic trends and meaningful ecological boundaries (Yohe and Tol, 2002).

4. Conclusion: combining environmental and social indicators

The goal of studying how environmental pathways interact with the local social context uncovers basic relations between society and the environment. In doing so we expect to make a modest contribution to the debate on the relation between society and the environment. By mapping these chains through a landscape, we can understand how humans interact with, affect, and are affected by environmental conditions. Initially, extensive work in a limited number of watersheds collecting household data on socio-economic pathways, and inputting this information onto a GIS that includes baseline environmental information is needed. We will then have a better understanding of how specific communities obtain their livelihoods from the landscape that surrounds them and how their interaction with that landscape affects their vulnerability to environmental change. We suggest that the process of analyzing the networks of social and economic activity through a landscape will allow researchers to determine generic characteristics of areas that are vulnerable to disruption if the social, economic or biophysical environment changes. After extensive replication, an analytic model will be developed that we anticipate will provide insight into the challenging relation between society and the environment through using environmental sensitivity and social resilience as dependent variables.

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