Advancing a Diagnostic Approach to Addressing Environmental Problems

Michael Cox[1]

Abstract:

Social-ecological systems exhibit patterns across multiple levels along spatial, temporal, and functional scales. The outcomes that are produced in these systems result from complex, non-additive interactions between different types of social and biophysical components, some of which are common to many systems, and some of which are relatively unique to a particular system. These properties, along with the mostly non-experimental nature of the analysis, make it difficult to construct theories regarding the sustainability of social-ecological systems.

This paper builds on previous work that has initiated a diagnostic approach to facilitate analysis of these systems. The process of diagnosis involves asking a series of questions of a system at increasing levels of specificity based on the answers to previous questions. The answer to each question further unpacks the complexity of a system, allowing an analyst to explore patterns of interactions that produce outcomes. An important feature of this approach is the use of multiple levels of analysis. As this paper will show, this feature can be used to analyze a diversity of environmental problems. Following this discussion, the implications of such a diagnostic approach for future research and pedagogy in the field of environmental management and policy are explored.

Keywords: diagnostics, panaceas, institutions, social-ecological systems

[1] Workshop in Political Theory and Policy Analysis, Indiana University

INTRODUCTION

Modern society faces a diversity of environmental problems including biodiversity loss, diminishing natural resource stocks, and a changing climate. Humans have developed a range of institutional responses in order to deal with many of these problems, with varying degrees of success. Unfortunately, our ability to explain and learn from this variation has been limited by the lack of an interdisciplinary scientific approach that can integrate different cases and their mix of social and biophysical features.

In order for scholars and practitioners to accumulate knowledge about how to best approach and resolve a variety of environmental problems, a consistent taxonomy of both the problems themselves and the possible solutions needs to be formulated. With this, patterns relating particular types of problems with certain institutional arrangements and resultant outcomes can be uncovered, and mechanisms behind those patterns can be explored. Institutional prescriptions can then be made by matching a particular type of problem to a particular type of institutional design. This is a diagnostic approach to social-ecological analysis. Such an approach has been described by Young (2002, 176):

> The diagnostic approach seeks to disaggregate environmental issues, identifying elements of individual problems that are significant from a problem-solving perspective and reaching conclusions about the design features needed to address each of the elements identified.

The motivation for diagnostic thinking is to devise responses to problems to which they are appropriately tailored. Implicit in this is the empirically well-established premise that no one solution can be successfully applied to all problems. This has been found both in medicine, which has substantially advanced the diagnostic approach, as well as environmental management and policy analysis (Ostrom 2007, 2009; Meinzen-Dick 2007; Ostrom and Cox 2010). In avoiding this blueprint problem, the governing principle of a diagnostic approach is to treat similar problems similarly, and different problems differently. Of course two problems may be similar in some dimensions and different in others, which ultimately requires a more nuanced approach, which can be developed.

This paper has two primary goals. The first is to progress this diagnostic approach. This will be done by showing how it can be benefited by the use of multiple levels of causation. With the help of this device this paper will show how a diagnostic approach has, at least implicitly, been applied in several separate research programs that focus on environmental management and policy analysis. This discussion can serve as the basis for further developing the diagnostic approach to a variety of types of environmental problems. The second goal of this paper is to explore some of the implications this new approach would have on the pedagogy and future research of environmental management and policy analysis.

DIAGNOSING SOCIAL-ECOLOGICAL SYSTEMS

Previous work has been done to develop the diagnostic approach discussed here (Ostrom 2007, 2009; McGinnis 2010). A key feature of this work is the presence of multiple levels of analysis, with varying levels of specificity across levels. Figures 1 and 2 show the first and second levels of a framework currently in development for diagnostic analysis of social-ecological systems (SESs). The first level is more aggregated, containing the main components of a SES. The second level contains properties of these components, and subsequent levels further unpack these properties, as shown in figure 2 (see Brock and Carpenter 2007; Meinzen-Dick 2007; Ostrom and Cox 2010).

[Figure 1 here]

[Figure 2 here]

This arrangement is important for a diagnostic approach as outlined earlier, which asks a series of questions at increasing levels of specificity based on answers to previous questions. Having an arrangement of multiple levels of analysis facilitates such a series of questions. The dependence of subsequent questions on answers to previous questions, and the concomitant typological decomposition of the system under analysis, is important for several reasons. First, it helps avoid the blueprint problem by facilitating prescriptive predictions at multiple levels of specificity, as is warranted by current knowledge. Secondly, it helps to deal with the potentially overwhelming complexity of SESs. If there is no arrangement of multiple levels, at least implicitly, then an analyst would have to explore an extremely large number of variables for each system (all the potentially relevant variables), which presents a problem for research design and methodology (Agrawal 2003). Missing values for important variables can lead to erroneous conclusions because of interaction effects and missing variable bias.

For example, if an analyst is examining the use of a forest ecosystem, he or she will likely need to ask some questions about ecological interactions and other important biophysical features such as soil properties (Tucker et al. 2007). However, if he or she is examining a groundwater aquifer system that is in use, ecological interactions become less important, while implementing environmental monitoring of the resource may become more technologically complicated, giving rise to an alternative set of questions. All variables need not be explored for each case: “The choice of relevant second or deeper levels of variables for analysis (from the large set of variables at multiple levels) depends on the particular questions under study, the type of SES, and the spatial and temporal scales of analysis” (Ostrom 2009, 420).

LEVELS OF CAUSATION

The SES approach described above employs multiple levels of analysis, which is important for a diagnostic approach. This work has not yet explored the use of multiple levels of causation. This paper demonstrates the utility of having such levels, leaving their incorporation into a fully developed diagnostic approach for future work. These levels are generally arranged from being in some way closest to the outcome obtained, to being more distanced but frequently more encompassing or complete in their explanatory power. While discussed as dichotomies, in effect there is more of a continuum or chain of causation present in complex systems.

The language of causation is extremely important for a diagnostic approach, because it provides a potential mechanism for the amelioration of an outcome by adjusting the cause of the outcome. Multiple levels of causation make this language more powerful. A basic question that a diagnostician might ask is, what are the proximal vs. distal causes of a particular outcome or problem? To fully understand an outcome, we need to understand both types of explanations, and the complex webs of causation that they evoke. Additionally, in different situations ameliorating a problem may be more easily or effectively done by addressing either a proximal or a distal cause.

Different disciplines have introduced multiple levels of causation in or order to sort out explanations of complex phenomena. Within the discipline of biology and research in evolutionary processes, a distinction between proximate and ultimate causes has been most popularized by Ernst Mayr (1961, 1988). In this context, a proximate cause explains a mechanism an organism has adopted to achieve a particular outcome, and an ultimate cause explains the proximate cause in evolutionary terms, or why this behavior or quality is adaptive. For example, Stephenson (1981) first explains how a variety of flowers are able to shed a portion of their developing flowers and fruits (proximate cause), and then discusses why this may be an evolutionarily adaptive behavior (ultimate cause).

Ariew (2003, 564), using evolutionary instead of ultimate as his preferred term, gives a description of the distinction that is useful for this discussion:

> Reference to proximate causes answer various questions including, ‘How does something get built?’ and ‘How does something operate?’ Evolutionary explanations (which substitute Mayr’s ‘ultimate cause’) … are statistical explanations that refer to ensemble-level events that track trends in populations rather than the vagaries of individual-level causal events. By averaging out individual-level differences, evolutionary explanations pick out patterns in common to all evolutionary events.

A slightly different distinction has arisen within the public health and epidemiological literature, examining proximal vs. distal causes of risk factors for disease. This is not, or is less, in the context of an evolutionary process with natural selection occurring, but it displays some similarities with proximate and ultimate causation from evolutionary research. Here, proximal causes may refer to those individual-level features that explain a health outcome for an individual, while distal causes may refer to social patterns that statistically relate features found within a population to the rate of incidence of diseases. For example, a proximal cause for a heart attack could be hypertension, while a more distal cause could be socio-economic status (Link and Phelan 1995). The statistical interpretation of ultimate causes presented by Ariew (2003) is applicable to distal causes in this context.

Finally, some scholars within the discipline of land change science studying environmental processes, particularly deforestation, have found this proximal-distal distinction useful (Ojima et al. 2001; Geist and Lambin 2002; Carr 2004; Turner et al. 2008). Based on a meta-analysis of 156 cases, for example, Geist and Lambin (2002) list several proximal causes of tropical deforestation (agricultural expansion, wood extraction, and infrastructure) and several underlying causes (including market growth, government policies, and technological change).

While the above research programs use separate terms, I will use the terms proximal and distal in this article to refer to two causes, one of which is causally prior to the other. The terms proximal and distal have a spatial connotation that is potentially accurate or misleading. The significance of the distinction is that a proximal cause is more specific to a particular system or observation, while its distal correlate explains its mechanistic significance by associating it with a broader phenomenon. It helps to explain the presence of the proximal cause itself. Distal does not mean a cause is more distant in strength of effect, or is somehow weaker. Distal causes do tend to be less internal to the system under analysis, describing a process that takes place externally, or at the interface between a system and its environment.

APPLICATIONS OF DIAGNOSTIC THINKING

There are several distinct research programs focused on environmental management and policy. Historically there has not been a lot of communication between these different programs. This paper briefly explores two such programs—one on the community-based management of common-pool resources, and the other, policy instrument choice of environmental pollution problems. This discussion will aim to show that each of these has implicitly used a diagnostic approach in the past, offering the tempting possibility that ultimately such an approach could be used to explore previously isolated environmental problems in ways that are complementary to each problem.

Community-based management

The study of community-based natural resource management systems is a well developed research program. One strand of this research program has occurred at the Workshop in Political Theory and Policy Analysis at Indiana University. This has involved several programs that develop databases of a large number of community-based systems (Ostrom 1990; Schlager 1990; Tang 1992; Lam 1998; Agrawal 2005; Hayes 2006; Ostrom and Nagendra 2007; Cox et al. 2010).

A result of the first of these endeavors was Ostrom's design principles (1990) for successful community-based natural resource management. Ostrom had searched for specific rules that characterized successful long-term community-managed systems. However, not finding any that were generalizable, Ostrom turned to a higher level of aggregation, which she referred to as design principles for successful long-term community management. That Ostrom had to appeal to a higher level of aggregation to achieve generalizability is not surprising in light of a principle formulated by Levin (1999), that at higher levels of aggregation more consistent patterns can be found among a set of observations.

As noted by David Sloan Wilson (2010), this discussion of Ostrom's design principles can be aided by using the distinction between ultimate and proximate causation from the evolutionary framework. As Wilson states:

> Ostrom initially attempted to correlate the success of each group with specific proximate mechanisms. Because there are many ways to skin a cat, the proximate mechanisms that work successfully in one group need not operate in other successful groups, resulting in weak correlations in a statistical analysis. When Ostrom started to focus on design principles, she was studying ultimate causation. The design principles are required for success, no matter how they are implemented, resulting in strong correlations. Of course, studying or advising any particular group would require close attention to both ultimate and proximate causation.

Ostrom's design principles have been criticized by encouraging a blueprint approach to policy analysis (Cox et al. 2010). This charge is concerned with the potential prescriptive application of policies that do not capture important features of a local context. Using the proximal-distal distinction helps us to examine this issue. As Wilson indicates, "there are many ways to skin a cat." Each principle can be satisfied by a range of proximal conditions, and thus a prescription for an institutional design principle is not as constraining, and less of a blueprint imposition, as a more proximal prescription (a particular rule) would be.

Ariew (2003) offers a helpful distinction between individual fitness and trait-fitness, where individual fitness results from proximal causes, and trait-fitness relates to distal causes. The design principles confer trait-fitness, or the average robustness of the systems that have these traits. This statistical, or non-deterministic, quality is important to emphasize. In their review of the literature written since the introduction of the principles, Cox et al. (2010) find that none of the principles guarantee success in their presence or failure in their absence. Likewise, having a trait that, at the level of the population is correlated with increased fitness, does not guarantee a high level of individual fitness for a particular organism.

Sloan Wilson makes another important point: that the study of a particular case requires that we look at both proximal and distal causes. Neither obviates the need for the other. This example from the literature on community-based natural resource management illustrates how multiple levels of causation, as initially established in work on evolutionary processes, can help us think more diagnostically and avoid the blueprint problem. We now turn to another literature with strong normative implications for how natural resources might be managed.

Policy instruments and climate change

Historically, there has not been a close connection between the commons literature, which has tended to emphasize small-scale community-based systems, and the literature on environmental economics and policy instrument choice[2], which has tended to focus on larger-scale environmental pollution problems. A concern of many critics of the commons literature is that it has tended to focus on relatively small-scale systems, and may not be very applicable to larger scale problems that the world is currently facing. A basic premise argued for in this paper is that a diagnostic approach could ultimately offer some integration of these two and other environmental research programs.

A focus on policy instrument choice is appropriate here because it is a field with large normative implications. It is oriented not just towards explanation or description, but prescription. Research on environmental policy instrument choice has, at least implicitly, taken a diagnostic approach by asking a series of questions, the answers to which have implications for the choice of the best policy instrument. The standard taxonomy of instruments initially breaks them down into command-and-control instruments and market-based instruments. The initial set of diagnostic questions asked are as follows: first, is there evidence of a market failure that leads to a divergence between private and social interests? Secondly, what is the type of failure? Is it, for example, a positive or negative externality, imperfect competition, information asymmetry, or a monopoly? The institutional design implications for each type of failure differ, as they should in a diagnostic approach.

For example, in the presence of uncertainty, variations in marginal benefits and marginal costs affect the extent to which price or quantity controls should be imposed (Weitzman 1974). As another example, in the presence of thin markets, a market-based approach to pollution may be less desirable, because it can lead to “hot spots” of pollution that can cross important ecological thresholds to cause higher levels of aggregate damage across the target area of the program. Meanwhile, market-based solutions to pollution are encouraged when the costs of pollution control varies dramatically between point sources.

The efficacy of an instrument may likewise vary with features of the pollutant.
The U.S. acid rain programs are seen as an extremely effective implementation of a cap-and-trade program to control SO_2 (as well as No_x). This has been suggested as a way of controlling other pollutants, such as mercury and CO_2. Mercury, however, does not mix well with the larger atmosphere and deposits close to its source of emission, which can lead to the hot spots previously mentioned. Likewise, the potential efficacy of this system to control CO_2 emissions is complicated by important differences between

[2] Rose (2002), as an exception to this tendency, offers an interesting discussion of the various conditions under which community-based or market-based management may be most appropriate.

SO_2 and CO_2 as pollutants. These include: 1) CO_2 is much less of a point source-based pollutant than is SO_2, which would facilitate market-trades among large sources with low transaction costs; 2) the causes and the effects of the pollution are global, dramatically increasing transaction costs (monitoring, enforcement) involved in remediation; 3) the effects of pollution are substantially lagged, lowering the feedback mechanism needed to incentivize implementation and to facilitate learning from various attempts at remediation.

We can further understand the issue of CO_2 emissions and resultant climate change with the use of multiple levels of causation. Within the economic literature on climate change, there is a distinction between adaptation and mitigation (Stern 2007). Mitigation generally involves attempts to lower the amounts of CO_2 contained in the atmosphere, while adaptation involves methods for adapting to the effects of higher temperatures and other changes that result from a strengthened greenhouse effect.

Mitigation efforts include policy-based methods such as cap-and-trade systems, renewable energy subsidies or reforestation policies, as well more technical geo-engineering methods, such as aerosol emission, oceanic cloud-seeding, and carbon sequestration. Adaptation methods are specific to the effects of climate change on systems that have been identified as important socially or ecologically. These impacts include changes in long-term averages of temperature or water availability and increasingly large fluctuations about those averages, changing species distributions, and rising sea levels. Generally, “adaptations can take technological, economic, legal and institutional forms” (Smit et al. 2000, 224).

In the language discussed earlier, these two approaches, adaptation and mitigation, address the proximal and the distal causes of a variety of problems. This application is most similar to the way these concepts are used in the land-use change literature mentioned earlier. For example, invasive species are a problem in many parts of the world. These can be considered a proximal cause for the disruption of local ecologies and food webs. In many cases, the distal cause is a changing climate that results from an increased greenhouse effect. Adapting to the introduction of a species (adaptation) can take a variety of forms. If the distal cause could be addressed, however, this could resolve the problem for systems suffering a variety of proximal effects. This is analogous to addressing a distal cause of poor health, such a socio-economic status, rather than intervening to ameliorate a variety of proximal mechanisms. Here again, a proximal cause is more specific to a particular system, while a more distal cause helps to explain the proximal cause and is shared by more systems.

As these examples illustrate, there is an established, if implicit, strain of diagnostic thought within the environmental economics and policy choice literature and the economic literature on climate change. At the same time, it could probably be benefited from a more explicit incorporation of proximal/distal thought, the way Ostrom implicitly did in her design principles. If we are to build on this basis and previous work on diagnosis of social-ecological systems to advance a unified diagnostic approach, we need to also explore the implications that this approach has for future research and pedagogy of environmental policy and analysis. We now turn to this topic.

IMPLICATIONS FOR PEDAGOGY

The implications of this discussion for pedagogy depends on what kind of expertise we wish to develop. The complexity of SESs and the interactions that make it difficult to generalize the dynamics of any one of them suggests that the kind of expertise we need is the ability to recognize patterns of such interactions. As Wilson (2002, 337) states: "the fundamental basis for learning and prediction in this kind of environment is the recognition of patterns."

Research in several fields has found that expertise is substantially a function of pattern recognition. In the game of chess, for example, de Groot (1946) found that expertise was dependent on the ability to recognize many different patterns of piece positions. Chase and Simon (1973) and Simon and Chase (1973) similarly developed an influential theory of expertise, whereby it is seen as a function of having a large number of complex patterns, which they called chunks, available for recognition and retrieval. Pattern recognition is also important in the diagnostic expertise of doctors, as discussed by Ericsson (2003, S77):

> During medical school and residency, there is not just an increase in accuracy of the diagnosis of common representative diseases, but there is also a change in the structure of diagnostic reasoning. With more clinical experience, biomedical reasoning during diagnosis is replaced by pattern recognition of disease schemas, which entail higher-level clinical concepts with encapsulated inferences.

Wilson (2002) refers to an example discussed by Holland (1998), where Holland describes the methods used by a checkers player to help them manage the many possible configurations of pieces that are possible during any game. These include the use of broad conditions, such as "net penetration beyond center line" that have a similar one-to-many relationship between the condition and number of board configurations as Ostrom's design principles do to particular sets of institutional arrangements. It is similarly plausible that the proximal vs. distal causal distinction could be employed in order to explain why one checkers player beats another. Wilson (2002) likens this approach to mastering the game of checkers to a process that could enable understanding of complex ecosystems.

This brief discussion illustrates a very important point: pattern recognition uses multiple levels of analysis itself, aggregating from many configurations into summary conditions at a more aggregated level of analysis. There is thus a close connection between the diagnostic approach, with an emphasis on multiple levels of analysis, and a pedagogy oriented towards developing expertise in pattern recognition.

The question we have to ask ourselves at this point is, what types of experiences facilitate the ability to recognize patterns? There is evidence (Ericsson 2003) that an important factor is direct and cumulative experience with many cases of the medium of expertise, whether it is a game of chess, medical diagnosis, or a case of environmental management. We can call this problem-based experience. To the extent to which this is true, it has implications for how expertise would be best developed in a formal educational setting.

The field of medicine, which has a highly developed diagnostic approach, has incorporated a problem-based methodology into its teaching and its research. Medical students are run through a variety of cases during their formal education, and the New England Journal of Medicine (NEJM), a premier journal in the field of clinical medicine (if not the premier journal), has a section devoted to descriptions of clinical cases from Massachusetts General Hospital. These are described here (Harris 2003, 2252):

> Virtually every physician in the world has, at one time or another, read the Case Records of the Massachusetts General Hospital in the Journal. Based on the case method of teaching medicine espoused by Dr. Walter Cannon, these conferences were established by Dr. Richard Cabot, an internist and faculty at Harvard Medical Schoon, during the first decade of the 20th century. Under his direction, the teaching of medicine through the study of 'actual cases of disease' became a popular feature at Harvard Medical School, at the Massachusetts General Hospital, and in the Journal, where the Case Records have been published since 1923.

Of course students and teachers of environmental management and policy pursuing a problem-based approach would have a different task than those in the medical field, where cases are available first-hand on a daily basis in the form of patients, and data collection on such patients is comparatively cheap. It is not feasible to expect an educational institution to have the resources to directly expose its students to specific environmental cases in the field. One substitute could be the documentation of cases within existing literature. This could be aided by having a section in an environmental studies or policy journal devoted to case studies based on the model developed by the NEJM. While in some respects this is a poor substitute, given resource constraints it is nevertheless likely a vital source of the development of expertise as outlined here. As Ericsson (2003**,** S74) notes, elite chess players have a similar problem:

> It is not obvious how an advanced chess player, who can easily beat all others in the chess club, can improve in this unchallenging environment…Chess players typically solve this problem by studying published games between the very best chess players in the world.

A problem-based curriculum stands in contrast with the formal education of most policy analysts in the U.S. With the exception of the instrument choice literature discussed earlier, the standard education of economic and policy analysts mostly lacks this perspective. Instead, standard curricula are more often characterized by a microeconomic and macroeconomic approaches, including courses such as econometrics, program evaluation, and cost-benefit analysis. These are a priori tools that can be applied to any particular study, but do not themselves constitute the direct experience needed for the development of expertise in environmental management and policy as I have defined it. While these are not necessary antithetical to a more problem-based and diagnostic approach (particularly econometrics and statistical analysis, which are certainly complementary), a strong emphasis on them can come at the expense of a more problem-based approach.

IMPLICATIONS FOR RESEARCH

Adopting a more problem-based, diagnostic approach to research in environmental policy and management is complicated by several factors. First, ecosystems and SESs contain more variables and can occupy more states than a game of checkers or chess. The costs of collecting data on these variables for a SES can be much higher than it is for collecting data on a patient in a hospital. SESs frequently exhibit low levels of feedback and substantial hysteresis, which make learning and adaptation very difficult. Global-scale problems with high levels of irreversibility such as climate change do not offer much opportunity for diagnostic learning at the global scale. For this reason, and for others, maintaining and producing a high level of institutional diversity (Ostrom 2005) will greatly facilitate this diagnostic approach in research. Global scale problems can be addressed a multiple scales, and smaller scales offer more opportunities for experimentation, learning, and pattern recognition.

Another challenge to the diagnostic approach is the fact that the values of important variables, which one uses as a basis for a institutional or technological prediction and prescription, may be endogenous to changes made in implementing this very prescription. This can result from the reactive and strategic behavior of human actors in SESs, as well as complex ecological interactions between ecological agents. Holling and Meffe (1996, 330) refer to a kind of failure to recognize this endogeneity as the pathology of natural resource management, and argue that negative outcomes can be expected from “a command-and-control approach to renewable resource management, where it is believed that humans can select one component of a self-sustaining natural system and change it to a fundamentally different configuration in which the adjusted system remains in that new configuration indefinitely without other, related changes in the larger system.” They cite pest outbreaks and excessive forest fires as examples of such negative outcomes. Endogeneity of supposedly independent variables is a problem for causal inference in social science generally (King et al. 1994). In recognizing this endogeneity, the diagnostic approach needs to be consonant with the research program in adaptive environmental management (Holling 1978).

A problem-based diagnostic approach also has implications for the kinds of methods and theories we might employ to meet these challenges and advance it as a novel research program. The pattern-based theories needed in the presence of high complexity and interaction effects are referred to by George and Bennett (2005, 235) as *typological theories.* A typological theory is “a theory that specifies independent variables, delineates them into the categories for which the researcher will measure the cases and their outcomes, and provides not only hypotheses on how these variables operate individually, but also contingent generalizations on how and under what conditions they behave in specified conjunctions or configurations to produce effects on specified dependent variables."

Typological theories are important in their ability to include potentially confounding variables that can lead to spurious correlations through interaction effects. It is of course impossible to eliminate every assumption made in constructing a theory, but the process of multi-level diagnostic thinking described earlier can help in this regard by guiding an analyst towards the variables that are likely to be most relevant in a particular context.

The expression of a hypothesis based on a typological theory is different from more general theories and hypotheses, which in the social sciences are frequently expressed through quantitative equations. George and Bennett (2005), for example, illustrate a typological theory through a causal diagram. In a relevant empirical example from the land cover change literature, Geist and Lambin (2002), having conducted a meta-analysis of the proximal and distal causes of deforestation, present their data as a causal diagram to explore the configurations of various causes of each type that lead to deforestation.

A causal diagram is a potentially useful way to explore typological theories, hypotheses, and research results. Greenland et al. (1999) present a formalization of causal diagrams from in the field of epidemiology, and figure 3 presents an example of a very simple causal diagram, where each arrow indicates causation. Such formalization is required in order to employ such representations in a scientifically rigorous and cumulative fashion. At the least it establishes a common set of terms to facilitate consistent use and understanding across studies.

[Figure 3 here]

In this context a causal diagram is presented as a network of variables. Each variable is a vertex or edge and the connections between them are causal arcs. As causation is a directed relationship, these arcs are likewise directed, pointing from a cause to an effect. "A path through the graph is any unbroken route traced out along or against arrows or lines connecting adjacent nodes" (*Ibid*, 38). A variable can be connected to another variable through as a path either as a cause, or as a common effect of another cause.

Greenland et al. (1999) demonstrate how these and other terms together with a diagrammatic presentation can facilitate an understanding of cause and effect and account for potential confounders in epidemiology. Such formalization is also complementary to the multiple levels of causation discussed earlier. Adjacent edges represent proximal causal relationships, whereas less direct relationships in the graph represent more distal causal relationships. For example, in figure 3, B is more proximal to C than is A.

CONCLUSIONS

This paper has attempted to make the case that a diagnostic approach could serve as a common logic through which many disparate types of environmental problems could be synergistically addressed, while avoiding the historically prevalent blueprint problem. The example of this common logic shown here is the use of multiple levels of causation. This is shown here to be useful in both community-based natural resource management and in the analysis of climate change policy, two fields with large normative implications, but without much historical overlap in the academic literature.

The potential for a more explicitly unifying approach has implications for both pedagogy and research. As it stands, pedagogy in the United States diverges from a model that would be more conducive to the development of diagnostic expertise in the field of environmental management and policy. The policy instrument choice literature suggests that there is an implicit strain of diagnostic thought in the education of young policy analysts that could be built on.

This paper has also discussed several challenges that face such an approach. This paper is highly exploratory, and much additional work will need to be done to clarify concepts and their relationships, and to test these with empirical work. In spite of these challenges and the work that remains, hopefully this paper has illustrated that a diagnostic, problem-based approach to education and research in this field has much to offer as an organizing logic for addressing a diversity of environmental problems.

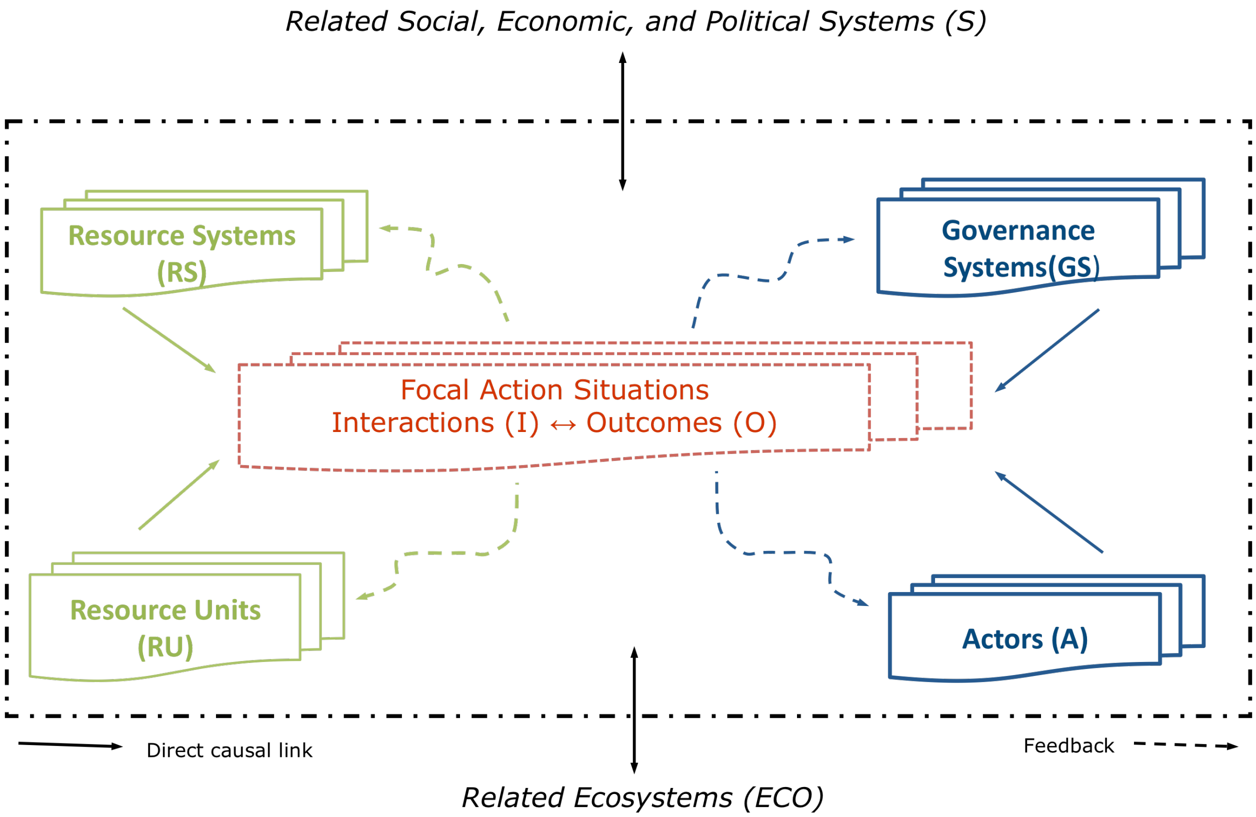

Figure 1: Level 1 of the SES framework (Source: Adapted from McGinnis 2010)

Level 1

Levels 2 and 3

Resource system

1) Sector: Groundwater
2) Boundary clarity
3) Size of basin
    a) Area
    b) Volume
4) Infrastructure
    a) # of wells
    b) Average well depth
5) Productivity
6) Equilibrium properties
    a) Recharge dynamics
    b) Recharge rate
    c) Number of equilibria
    d) Feedbacks
        a) Positive
        b) Negative
7) Predictability
8) Storage capacity
    a) High or low
9) Location
10) Confined to unconfined

Governance system

1) Rules
    a) Operational rules
    b) Collective choice rules
    c) Constitutional rules
2) Property rights regime
3) Network structure
    a) Centrality
    b) Modularity
    c) Number of levels

Action situation

1) Process
    1) Monitoring
        a) Environmental
        b) Social
    2) Sanctioning
        a) Graduated
    3) Conflict resolution
    4) Provision
        a) Informational
        b) Infrastructural
    5) Appropriation
    6) Policymaking

Figure 2: Levels 2 and 3 of the SES framework (Source: Adapted from Ostrom and Cox 2010)

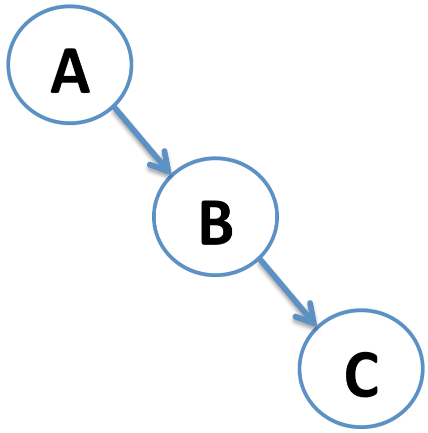

Figure 3: A simple causal diagram

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