A diagnostic approach for going beyond panaceas

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The articles in this special feature challenge the presumption that scholars can make simple, predictive models of social–ecological systems (SESs) and deduce universal solutions, panaceas, to problems of overuse or destruction of resources. Moving beyond panaceas to develop cumulative capacities to diagnose the problems and potentialities of linked SESs requires serious study of complex, multivariable, nonlinear, cross-scale, and changing systems. Many variables have been identified by researchers as affecting the patterns of interactions and outcomes observed in empirical studies of SESs. A step toward developing a diagnostic method is taken by organizing these variables in a nested, multitier framework. The framework enables scholars to organize analyses of how attributes of (*i*) a resource system (e.g., fishery, lake, grazing area), (*ii*) the resource units generated by that system (e.g., fish, water, fodder), (*iii*) the users of that system, and (*iv*) the governance system jointly affect and are indirectly affected by interactions and resulting outcomes achieved at a particular time and place. The framework also enables us to organize how these attributes may affect and be affected by larger socioeconomic, political, and ecological settings in which they are embedded, as well as smaller ones. The framework is intended to be a step toward building a strong interdisciplinary science of complex, multilevel systems that will enable future diagnosticians to match governance arrangements to specific problems embedded in a social–ecological context.

commons | complexity | governance | interdisciplinary research | sustainability science

What Can Be Done?

In the introduction to this special feature, we call attention to perverse and extensive uses of policy panaceas in misguided efforts to make social–ecological systems (SESs), also called human–environment systems, sustainable over time. It is not enough, however, just to call attention to the inadequacy of the panaceas that are prescribed as simple solutions to complex SESs. Korten (1) long ago identified the danger of blueprint approaches to the governance of tough social–ecological problems and urged that policy makers adopt a learning process rather than imposing final solutions. Korten's advice is similar to that of Walters (2, 3) and the emphasis on adaptive management in contemporary analyses of complex adaptive systems (4–6). Unfortunately, the preference for simple solutions to complex governance problems continues to be strong (7).

To move beyond panaceas and build a solid field of sustainability science (8, 9), one needs to build on the work of scholars who have undertaken careful, well documented and theoretically sound studies of ecological systems, socioeconomic systems, and linked SESs (10–17). We should stop striving for simple answers to solve complex problems (18). The problems of overharvesting and misuse of ecological systems are rarely attributable to a single cause (19). Holling *et al.* (ref. 20, p. 352) identified the structure of the problems involved:

> The answers are not simple because we have just begun to develop the concepts, technology and methods that can address the generic nature of the problems. Characteristically, these problems tend to be systems problems, where aspects of behaviour are complex and unpredictable and where causes, while at times simple (when finally understood), are always multiple. They are non-linear in nature, cross-scale in time and in space, and have an evolutionary character. This is true for both natural and social systems. In fact, they are one system, with critical feedbacks across temporal and spatial scales.

The conceptual structure of these problems is a rugged landscape with many peaks and valleys. Finding higher peaks when the number of potential solutions is drastically reduced to a few "optimal" strategies is grossly inadequate for reaching creative and productive solutions to challenging problems (21). One can become fixated on a low conceptual hill by trying to optimize specific variables while overlooking better solutions involving ignored variables. Instead, we need to recognize and understand the complexity to develop diagnostic methods to identify combinations of variables that affect the incentives and actions of actors under diverse governance systems (22). To do this we need to examine the nested attributes of a resource system and the resource units generated by that system that jointly affect the incentives of users within a set of rules crafted by local, distal, or nested governance systems to affect interactions and outcomes over time (see Fig. 1). Furthermore, we need to enable resource users and their officials to experiment with adaptive policies so as to gain feedback from a changing SES before a severe transformation adversely overcomes them (23, 24).

A Nested Framework for Analyzing Interactions and Outcomes of Linked SESs

Moving beyond panaceas to develop cumulative capacities to diagnose the problems and potentialities of linked SESs requires serious study of the complex, multivariable, nonlinear, cross-scale, and changing SESs described by Holling *et al.* (20). We need to clarify the structure of an SES so we understand the niche involved and how a particular solution may help to improve outcomes or make them worse. Also, solutions may not work the same way over time. As structural variables change, participants need to have ways of learning and adapting to these changes.

Many variables affect the patterns of interactions and outcomes observed in empirical studies. After undertaking a careful analysis of the research examining the factors likely to affect self-organization and robustness of common-property regimes, Agrawal (25) identified >30 variables that had

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Abbreviations: GS, governance system; RS, resource system; RU, resource user; SES, social–ecological system; U, user.

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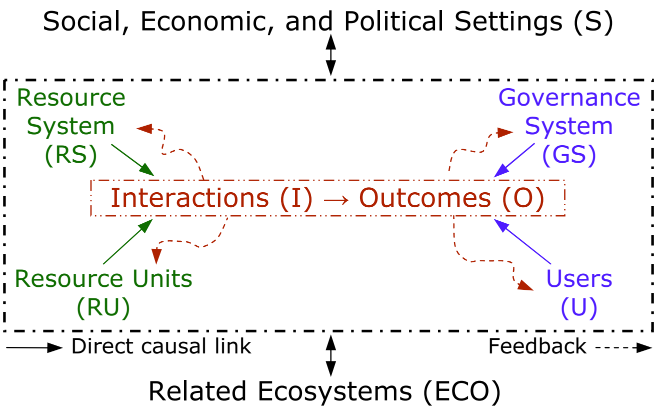

Fig. 1. A multitier framework for analyzing an SES.

been posited in major theoretical work to affect incentives, actions, and outcomes related to sustainable resource governance. Agrawal raises challenging questions about how research can be conducted in a cumulative and rigorous fashion if this many variables need to be identified in every study. Whereas scholars do need to learn how to identify and measure the variables that Agrawal identified, and an even larger number as shown in Table 1, all of these variables are not relevant in every study, because SESs are partially decomposable systems.

Decomposable Systems. Scientific progress has been achieved in the past when scholars have recognized that complex systems are partially decomposable in their structure (26–29). Simon (ref. 30, p. 753) describes nearly decomposable systems as being "arranged in levels, the elements at each lower level being subdivisions of the elements at the level above. . . . Multicelled organisms are composed of organs, organs of tissues, tissues of cells." Holland (31) has examined the parallel processes present in decomposable systems for balancing exploitation and exploration of adaptive systems.

Three aspects of decomposability of complex subsystems are important for achieving a better understanding of complex SESs and crafting ways to improve their performance. The first aspect is the conceptual partitioning of variables into classes and subclasses. The second aspect is the existence of relatively separable subsystems that are independent of each other in the accomplishment of many functions and development but eventually affect each other's performance. The third aspect is that complex systems are greater than the sum of their parts.

The first aspect, variables that are composed of classes and subclasses, must be understood to build coherent and cumulative scientific understanding (see Fig. 1 and Table 1). The second aspect, parallel functionality and adaptability, is essential for enabling long-term solutions to complex SESs. Policies can be explored in one part of a system without imposing uniform formulas on the larger system that might lead to a large-scale collapse. The third aspect makes it essential for scholars to recognize that combining variables, for instance *A*, *B*, and *C*, can lead to a system with emergent properties that differ substantially from combining two of the original variables with a different one, say *A*, *B*, and *D*.

Developing the Nested Conceptual Maps. Let us now address the importance of identifying the conceptual tiers and linkages among variables that constitute an SES as it affects and is affected by larger and smaller SESs. At the broadest conceptual level, one can posit a general framework, a conceptual map, that can be used as the starting point for conducting the study of linked SESs. Fig. 1 presents a simple, very general framework for what I hope captures the highest-tier variables that scholars must analyze when examining linked SESs.[†] At this broad level, one can begin to organize an analysis of how attributes of (*i*) a resource system (e.g., fishery, lake, grazing area), (*ii*) the resource units generated by that system (e.g., fish, water, fodder), (*iii*) the users of that system, and (*iv*) the governance system jointly affect and are indirectly affected by interactions and resulting outcomes achieved at a particular time and place. Using such a framework also enables one to organize how these attributes may affect and be affected by the larger socioeconomic, political, and ecological settings in which they are embedded, as well as smaller ones.

Each of the eight broad variables shown in Fig. 1 can be unpacked and further unpacked into multiple conceptual tiers.[‡] How far down or up a conceptual hierarchy a researcher needs to proceed depends on the specific empirical or policy question under investigation. If a researcher wishes to address the "regulating services" examined by the Millennium Assessment, the related ecosystem (ECO) variables would need to be further unpacked. Furthermore, many interactions and outcomes depend on the specific combination of several variables at one or multiple tiers (36–39). The direction and strength of impact of one-variable frequently depend on the other variables present (40, 41) and the past history of processes in the SES. Further use and development of this framework will hopefully enable researchers to develop cumulative, coherent, and empirically supported answers to three broad questions:

1. What patterns of interactions and outcomes, such as overuse, conflict, collapse, stability, and increasing returns, are likely to result from using a particular set of rules for the governance, ownership, and use of a resource system and specific resource units in a specific technological, socioeconomic, and political environment?
2. What is the likely endogenous development of different governance arrangements, use patterns, and outcomes with or without external financial inducements or imposed rules?
3. How robust and sustainable is a particular configuration of users, resource system, resource units, and governance system to external and internal disturbances?

Because this is a decomposable system, each of the highest-tier conceptual variables in Fig. 1 can be unpacked and related to other unpacked variables in testable theories relating the outcomes of human use of the diverse types of SESs. Table 1 lists major second-tier variables that have been shown in

[†]This framework further elaborates the Institutional Analysis and Development (IAD) framework developed by scholars at Indiana University (32) and the framework developed by Anderies *et al.* (33) for examining the robustness of SESs. See Meinzen-Dick (34) for a further elucidation of the general variables presented in the above framework (Table 1) for analyzing irrigation institutions and the greatly expanded and general version of this framework contained in the supporting information of Brock and Carpenter (35).

[‡]The task of identifying which variations are subcategories of a more general variable is not to identify the relative importance of a variable in a particular setting. Some crucial variables used in the design of successful governance systems are third- and fourth-tier variables that are important in these, but not in all, SESs.

Table 1. Second-tier variables in framework for analyzing an SES

Social, Economic, and Political Settings (S)	
S1- Economic development. S2- Demographic trends. S3- Political stability. S4- Government settlement policies. S5- Market incentives. S6- Media organization.	
Resource System (RS)	**Governance System (GS)**
RS1- Sector (e.g., water, forests, pasture, fish)	GS1- Government organizations
RS2- Clarity of system boundaries	GS2- Non-government organizations
RS3- Size of resource system	GS3- Network structure
RS4- Human-constructed facilities	GS4- Property-rights systems
RS5- Productivity of system	GS5- Operational rules
RS6- Equilibrium properties	GS6- Collective-choice rules
RS7- Predictability of system dynamics	GS7- Constitutional rules
RS8- Storage characteristics	GS8- Monitoring & sanctioning processes
RS9- Location	
Resource Units (RU)	**Users (U)**
RU1- Resource unit mobility	U1- Number of users
RU2- Growth or replacement rate	U2- Socioeconomic attributes of users
RU3- Interaction among resource units	U3- History of use
RU4- Economic value	U4- Location
RU5- Size	U5- Leadership/entrepreneurship
RU6- Distinctive markings	U6- Norms/social capital
RU7- Spatial & temporal distribution	U7- Knowledge of SES/mental models
	U8- Dependence on resource
	U9- Technology used
Interactions (I) →	**Outcomes (O)**
I1- Harvesting levels of diverse users	O1- Social performance measures (e.g., efficiency, equity, accountability)
I2- Information sharing among users	O2- Ecological performance measures (e.g., overharvested, resilience, diversity)
I3- Deliberation processes	O3- Externalities to other SESs
I4- Conflicts among users	
I5- Investment activities	
I6- Lobbying activities	
Related Ecosystems (ECO)	
ECO1- Climate patterns. ECO2- Pollution patterns. ECO3- Flows into and out of focal SES.	

empirical studies to impact diverse interactions and outcomes (17, 42–45), including all 30 variables identified by Agrawal (25) plus others. They are the initial core of conceptual variables needed to identify the broad type of SES operating at a particular location in time and space so an accurate diagnosis of the reasons for sustainable or unsustainable outcomes can be identified.

In addition to the broad second-tier variables identified in Table 1, many more specific variables are identifiable at deeper levels. The importance of specific third-tier variables is illustrated in the analysis discussed below of failed vs. successful SESs. Research is currently underway to develop this diagnostic framework further and link it to rigorous empirical research findings. A major challenge is defining all variables so the conceptual logic of linking more specific concepts to more general concepts is clear and open to further discourse and development. An extensive conceptual taxonomy related to governance systems has been developed during the past three decades (32). Table 1 draws on iterated nested frameworks developed by ecologists for identifying types of ecological systems [see, for example, Josse *et al.* (46), who identify nearly 700 types of ecological systems present in Latin America and the Caribbean].

In the complex and changing world to be studied and in theoretical models of that world, interaction effects often occur among variables at one or more tiers. The storage available in a system (e.g., the amount of water that can be stored in a dam or carbon that can be stored in a forest) may differ by resource system and resource units (39). One needs to dig into third- or fourth-tier variables and the horizontal linkages among them for a meaningful understanding of storage. Thus, one needs to examine both vertical and horizontal relations of a partially decomposable conceptual map and the temporal and spatial dimensions of systems (47).

The long-term goal for scholars of sustainability science is to recognize which combination of variables tends to lead to relatively sustainable and productive use of particular resource systems operating at specific spatial and temporal scales and which combination tends to lead to resource collapses and high costs for humanity. Instead of a simple system to analyze, scholars and policy analysts face compound puzzles nested in compound puzzles (48, 49). The key is assessing which variables at multiple tiers across the biophysical and social domains affect human behavior and social–ecological outcomes over time.

Conditions Leading to the "Tragedy of the Commons"

Using this framework, we can now reconstruct Hardin's (50) allegory to include a particular set of second-tier variables (Table 2). Hardin envisioned a pasture open to all in which each herder received a direct benefit from adding animals to graze on the pasture and suffered only delayed costs from overgrazing. Translating his metaphor into a theory requires five assumptions: (*i*) the resource system is a pasture (RS1); (*ii*) no governance system is present (no GS variables) related to the resource system; (*iii*) the mobile individual resource units (RU1, the animals grazing on the pasture) can be identified and are the property of their owners (implicitly assuming RU6) and, when fattened, can be sold for cash (RU4); (*iv*) a sufficient number of users (large U1), given the size of the pasture (RS3), are using the pasture to adversely affect its long-term productivity (RS5); and (*v*) the resource users independently make decisions to maximize their own short-term returns (U7). These five assumptions about second-tier variables lead to a theoretical prediction of very high harvesting of the pasture grasses (I1) and severe overharvesting or destruction of the ecological system (O2).

Using the framework to represent the small set of variables used in Hardin's theory (as shown in Table 2) helps to clarify that Hardin's influential work was based on an extremely sparse view of the commons. Situations characterized by these assumptions, in which individuals independently make anonymous decisions and primarily focus on their own immediate payoffs, do tend to overharvest open-access resources. Researchers have repeatedly generated a "tragedy of the commons" in experimental laboratories when subjects make independent and anonymous decisions in a common-pool resource setting (51–54).

Making one small change, however, in the structure of laboratory experiments, a change that is predicted by game theory to make no difference in the predicted outcome, has repeatedly had major impacts on interactions and outcomes (see refs. 51, 52, and 54). Simply enabling subjects to engage in face-to-face communication between decision rounds enables them to approach socially optimal harvesting levels rather than severely overharvesting the commons. In the face-to-face discussions, participants tend to discuss what they all should do and build norms (U6) to encourage conformance.

The Difference Between Roving Bandits and Harbor Gangs

In addition to carefully structured common-pool experiments that replicate Hardin's assumptions, SESs exist

Table 2. Second-tier variables used by Hardin (50) in "The Tragedy of the Commons"

Social, Economic, and Political Settings (S)
S1- S2- S3- S4- S5- Market incentives S6-

Resource System (RS)	Governance System (GS)
RS1- Sector — pasture	GS1-
RS2-	GS2-
RS3- Finite size	GS3-
RS4-	GS4-
RS5- Renewable resource	GS5-
RS6-	GS6-
RS7-	GS7-
RS8-	GS8-
RS9-	

Resource Units (RU)	Users (U)
RU1- Mobile animals on stationary grasses	U1- Large number of users
RU2-	U2-
RU3-	U3-
RU4- Fattened cattle can be sold for cash	U4-
RU5-	U5-
RU6- Distinctive markings	U6-
RU7-	U7- Maximization of short-term gains for self
	U8-
	U9-

Interactions (I) →	Outcomes (O)
I1- Maximum harvesting levels by users	O1-
I2-	O2- Destruction of ecological system
I3-	O3-
I4-	
I5-	
I6-	

Related Ecosystems (ECO)
ECO1- ECO2- ECO3-

in field settings lacking governance systems or opportunities for communication. Berkes *et al.* (55) examine the impact of roving bandits: fishing fleets that target valuable marine species in coastal waters, deplete local stocks, and then move on to exploit stocks located in other regions. Drawing on the work of Olson (56), who developed the concept of roving bandits, Berkes *et al.* (ref. 55, p. 1557) characterize the problem: "Roving banditry is different from most commons dilemmas in that a new dynamic has arisen in the globalized world: New markets can develop so rapidly that the speed of resource exploitation often overwhelms the ability of local institutions to respond."

These settings are similar to those characterized by the five assumptions that Hardin (50) implicitly made, with the exception of the first assumption related to resource systems: (*i*) the resource systems (RS1) are coastal waters rather than pastures. The other assumptions are very similar: (*ii*) no governance system is present (no GS variables) related to the resource systems; (*iii*) the mobile individual resource units (RU1, the fish captured by a fishing boat) become the private property of the boat owner and can be sold for cash (RU4); (*iv*) a large number of fishing boats (large U1), given the finite size (RS3) of the renewable fishery (RS5), are roving the coastal waters searching for schools of fish to harvest; and (*v*) the owners of fishing vessels make decisions independently to maximize their own short-term returns (U7). The only slight difference in assumptions is the third assumption related to the basis for establishing ownership of the resource units (capture as contrasted to long-term possession). The predicted interactions and outcomes (I1, high harvesting levels, and O2, severe overharvesting or destruction of the ecological system) do occur in the coastal waters studied by Berkes *et al.* (55).

Solving the problem of roving bandits for mobile ocean fisheries is more challenging than designing governance arrangements well matched to the smaller spatial scales of many local, common-pool resources (refs. 17, 44, and 57–59; see also the Digital Library of the Commons for extensive citations, http://dlc.dlib.indiana.edu). Berkes *et al.* (55) point to the need for multilevel governance institutions operating from local to international levels (see also refs. 47 and 60–63). They conclude that:

> no single approach can solve problems emerging from globalization and sequential exploitation. But the various approaches used together can slow down the roving bandit effects, and can replace destructive incentives with a resource rights framework that mobilizes environmental stewardship, i.e., one that builds the self-interested, conserving feedback that comes from attachment to place (ref. 55, p. 1558).

In contrast to the roving bandit problem, Acheson, Wilson, and colleagues (64–66) have documented how the lobster fishers of Maine recovered from a major crash of the lobster stock in their coastal waters during the 1920s and 1930s to experiment with a diversity of ingenious rules and norms well fitted to key attributes of the resource units, the lobsters, and how fishers were organized within their harbors.

Whereas the contemporary roving bandits of international waters simply move on after they destroy a stock, including the green sea urchins that were depleted from the Maine shore in the 1980s for export elsewhere, the lobster fishers of Maine have lived in shoreline communities for many generations (U3), have deep roots in their communities (U4) and local leadership (U5), have developed norms of trustworthiness and reciprocity with those with whom they have close interactions (U6), and have gained effective knowledge about the resource system and resource units they are using (U7) to evolve an ever more valuable local fishery, with sales of Maine lobsters totaling $186.1 million in 2000 (ref. 64, p. 13).[§]

The biological attributes of lobsters (the RU) have enabled the state government of Maine and the lobster fishers to develop harvesting rules and norms that have contributed to the recuperation of the stock (ref. 67, p. 1907; and Fig. 1). Lobsters are slow-growing but highly productive after reaching maturity at ≈7 years, with an expected lifespan of up to 100 years. Fishers sort through the catch in their traps and can safely return to the sea lobsters that are below and above a defined size as well as any "berried" female lobsters, easily identified by the hundreds of eggs extruded on their bellies.

However, as Wilson *et al.* (68) clearly demonstrate, local trap-fishers may evolve highly exploitative harvesting strategies, depending on the specific combination of attributes assumed in the model. The eventual success of the Maine lobster fishery is thus attributable to the congruence of multiple factors. The state of Maine made it illegal to harvest egg-bearing female

§Events in the rest of the ecosystem have turned the lobster fishery into more of a monoculture that exposes it to the threat of an epidemic among the lobsters that could generate an unexpected collapse at some future date. These problems cannot be addressed by the evolved lobster governance system alone (S. Carpenter, personal communication, August 1, 2006; and J. Wilson, personal communication, June 15, 2007).

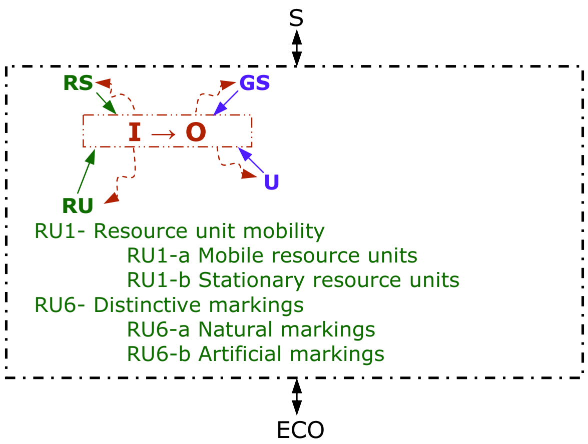

Fig. 2. Illustrative examples of second- and third-tier variables for resource units.

lobsters in the 1870s. This formal law was not effective, as many fishers simply scrubbed the eggs off berried females and sold them easily (64). In an effort to encourage the owners of lobster pounds not to harvest berried females, the state established a fund to buy back bearing-age females from pound owners. The warden would punch a hole in the lobster tail and anyone caught selling lobsters with punched holes could be prosecuted. In 1948, the law was changed to make it illegal to sell a lobster marked with a V-notch, which lasts two or possibly three molts, rather than a simple hole.

Soon thereafter, lobster fishers began voluntarily to V-notch berried lobsters caught in their traps as a way of marking a bearing-age female and to refrain from selling a V-notched lobster marked by another fisher. Common understanding and use of the norm grew over time and is now widely practiced (64). A reliable signal was created that could be easily monitored, and the fishers had a simple way of sanctioning noncompliance by destroying the traps of an offending fisher. The widespread use of V-notching helps to solve a core problem identified in the theoretical literature on collective action of establishing reliable signals to enhance reciprocity in collective efforts (69, 70).

This reciprocity norm would not be effective if in addition to the attributes of the resource users (U) described above, lobsters (RU) could not be returned to the sea to continue growth and reproduction for many years (RU2), if most lobsters initially caught in one harbor migrated to distant harbors (RU1-a), or if the V-notch disappeared rapidly (RU6-b) (see Fig. 2). Also important is that resource users are informally affiliated with others: a harbor "gang." Fishers living in each harbor have self-defined the outer boundaries of their territory over time. Wilson *et al.* (68) demonstrate that territoriality is unlikely to evolve spontaneously in a multiagent model unless fishers can potentially engage in trap cutting (a sanctioning mechanism) and retain memories of both good and bad events. Self-organized monitoring and enforcement have repeatedly played important roles in explaining successful efforts at collective action (52–54, 71).

Distinctive Markings of Resource Units and Property-Rights Systems

Although distinctive markings of a resource unit (RU6) are not discussed in the theoretical literature, they are frequently used as an important attribute of resource units in constructing effective property-rights systems (GS4). Pastoralists through the ages have claimed ownership of their animals by their natural distinctive markings when the number of animals involved is relatively small and individual units are easy to identify (RU6-a). Diverse property-rights systems make use of artificial markings of resource units (RU6-b) as ways of identifying private property or resource units that need protection. Branding became a method for giving a large number of cattle a distinctive marking in the "Wild West," where cattleowners' associations developed relatively large-scale governance systems involving an annual roundup and assignment of specific brands to the owners of cattle.

The territorial organization of lobster fishers in Maine takes advantage of the second major aspect of decomposability: the potential organization and governance of SESs at small to ever-larger spatial scales (GS). Given the tradition of local governance in Maine, the fishers have had considerable autonomy to develop and experiment with their own rules related to who fishes from which harbor, when the fishing season opens or closes, size limits, V-notch rules, and other local rules. In light of the exchange of information among localities, harbor organizations have learned of and adopted more effective rules that have then been backed by the state of Maine.

Conditions related to autonomy in making rules were also present when the green sea urchins were overexploited, but the fishers in this instance were not local (U2), did not share norms related to harvest levels and practices (U6), and rapidly exploited the stocks (O2) to sell for export (S5) before local fishers or officials (U5) took much note of the overharvesting. Lobster stocks have been sequentially overharvested in other locations where resource user characteristics differ (have not lived in the same harbor for generations, no strong local leaders, no local norms, and little autonomy to make their own local rules) (72). A major factor in converting roving bandits into effectively organized local groups is finding ways to convert the time horizon of harvesters from short term to long term. Harvesters with a long-term interest in the sustainability of a particular resource system are more likely to invest in rules and norms related to timing, technology, and quantity of harvesting and in generating useful information about resource conditions and the strategies of all harvesters.

Multiple Methods for Analyzing Complex Nested Systems

Hopefully, a recognition of the decomposability of the conceptual knowledge system needed for analyzing linked SESs at multiple spatial scales will help reduce the tensions that exist among advocates of a single research method for studying SESs. Just as advocating a single-policy panacea is not appropriate for crafting sustainable SESs, exclusive devotion to a particular research method threatens the capability of scientists to contribute to the development of the diversity of institutions needed to sustain the diversity of ecological settings over time. Researchers who undertake abstract analytical models keep their analyses to a simple set of variables, or they cannot find analytical solutions. We should not assume, however, that the assumptions of a particular model are characteristic of all SESs but rather of an important type of system with broadly relevant but specific attributes (35). What analytical differences result when one dips down a conceptual level and changes one or more assumptions? Hardin's (50) original set of assumptions are quite robust when it comes to predicting the outcomes of a system of roving bandits but are inappropriately applied to the inshore Maine lobster fisheries, and many (but not all) of other self-governed SESs, such as the irrigation systems discussed by Meinzen-Dick (34) and the forests discussed by Nagendra (73).

Researchers who prefer case studies sometimes presume that the third- or fourth-tier variables observed in their studies are present in most other broadly similar SESs. When scholars suggest that a particular variable is important, other researchers sometimes respond, "Not in my case!" with the implication that the variable would not be important elsewhere. The concept of nested tiers of variables that interactively affect how other variables help or do not help to explain outcomes is a challenge to the way many scholars approach theory and explanation. Scholars who prefer to collect large samples and use multiple regression or similar statistical techniques are initially horrified when a large set of variables is listed, given the cost of obtaining reliable indicators of the same variable across cultural settings. Mistakenly, they presume that all of these variables need to be measured and included in future research. Instead, third-, fourth-, and fifth-tier variables are potentially relevant only when they are subcomponents of a second-tier variable posited to affect interactions and outcomes.

Scholars who examine the patterns of interactions (I) and outcomes (O) for a large number of resource systems (RS) by undertaking metaanalyses of the case studies written by other scholars or by undertaking new research find that they must include a large number of variables like those identified in Table 1. A frustrating aspect of conducting metaanalyses is the large number of individual case studies that must be read and given initial codes to find cases with specific information about the core variables identified in Fig. 1 and Table 2. Pagdee *et al.* (74), for example, were able to analyze only 31 of a set of 110 case studies related to forest management involving some aspects of local participation. Many of these studies did not have sufficient information concerning outcomes, the resource system, resource users, or the governance system to be able to determine the factors associated with observed performance.

Colleagues at Indiana University systematically screened many cases before identifying a set of 47 irrigation systems (of 450 documents screened) (75) and 33 organized groups of fishers (also after screening several hundred documents) (76) with sufficient and reliable data to enter in a common-pool resource database and to analyze. Without a common taxonomy of core variables, research conducted by scholars from multiple disciplines tends to focus on variables of major interest to their own disciplines without recording, measuring, controlling for, or even thinking of other variables that might account for the patterns of interactions and outcomes observed (77, 78). In their effort to assess the effectiveness of diverse conservation strategies, Brooks *et al.* (79) also conducted a metaanalysis of empirical studies and found that researchers measured a wide diversity of variables rather than testing a common set of factors potentially associated with success. Agrawal and Redford (80) present a powerful critique of the lack of consistent measures across studies of SESs.

Thus, a generally accepted multitier nested framework will help scholars identify at what conceptual level their research is located and how research undertaken at multiple conceptual levels using diverse methods complements, rather than competes with, research using other methods and other levels. Without such a framework, further unnecessary research method "wars" will continue. Hopefully, the framework presented herein will stimulate further development of it so as to gain greater cumulative knowledge about the complex systems we are studying. By building and using a multitier conceptual framework, scholars can draw on all of the above methods as well as newer modeling techniques such as agent-based models (6, 81, 82), use of remotely sensed data combined with on-the-ground data (71, 83, 84), and statistical techniques, such as qualitative conceptual analysis (85–87).

Conclusion

We need a better understanding of decomposable, multitier SESs derived from systematic research that bridges the contemporary chasm separating biophysical and social science research. Furthermore, as we have learned from medical research, all prescribed cures may have unanticipated effects, depending on the combination of remedies used. Policy analysts need to study and record the unintended effects of particular policy interventions, so that dangerous combinations of policies devised at diverse tiers or attributable to particular aspects of a resource system and resource units can be avoided. Just as there is no cure-all that works in all settings, there is no ideal entry point for carrying out rigorous, useful research on linked SESs. The entry point depends on the question of major interest to the researcher, user, or policy maker. For some questions, the appropriate focal system is the broader social, economic, and political setting (S) in which one compares these broader settings over time and across space as they impact on the problem-solving capability of resource users (U) and the officials in a governance system (GS) as their interactions affect a resource system (RS) and resource units (RU). When one is examining a problem within a particular setting S (e.g., all RSs in a single country at one historical period) or where the RSs are located in isolated areas with weak impacts from the broader S, one may enter analysis by identifying a particular type of RS (e.g., forests in mountainous regions). Or one may start with a particular type of RS or GS and ask how these function in diverse, broader settings by beginning with a second- or third-tier variable and moving up to include first-tier variables to help explain the differences in outcomes.[¶]

We must keep in mind that broader as well as more specific variables may have an important role in explaining observed outcomes, depending on the question and resulting processes being examined. Identifying a clear question must always be the first step in analyzing linked SESs (89). Once we identify a good entry point for examining a particular question, we can then embed it in an analysis by using variables from multiple tiers. Or one may start as Berkes (90) has done by asking how to establish more effective conservation projects with active (as contrasted to nominal) participation. In his analysis, he uses the theoretical developments of complex adaptive systems to avoid a blueprint approach while advocating a conceptual approach closely related to the framework outlined above for diagnosing diverse conservation efforts. The framework presented in this article will obviously need further development. Hopefully, cumulative use of the framework to undertake better designed research, analysis, and policy proposals in the coming years will reduce the tendency to prescribe simple panaceas for solving the diversity of problems facing linked SESs.

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¶Carlsson and Berkes (ref. 88, p. 65) outline a series of steps for conducting policy analysis of comanagement systems: ''This kind of research approach might employ the steps of (1) defining the social-ecological system under focus; (2) mapping the essential management tasks and problems to be solved; (3) clarifying the participants in the problem-solving processes; (4) analyzing linkages in the system, in particular across levels of organization and across geographical space; (5) evaluating capacity-building needs for enhancing the skills and capabilities of people and institutions at various levels; and (6) prescribing ways to improve policy making and problem solving.''

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