

COPING WITH TRAGEDIES OF THE COMMONS

by

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## ABSTRACT

Contemporary policy analysis of the governance of common-pool resources is based on three core assumptions that (1) resource users are norm-free maximizers of immediate gains who will not cooperate to overcome the commons dilemmas they face, (2) designing rules to change incentives of participants is a relatively simple analytical task, and (3) organization itself requires central direction. The paper shows that these assumptions are wrong and a poor foundation for policy analysis. Findings from carefully controlled laboratory experiments are summarized that challenge the first assumption. A different assumption that humans are fallible, boundedly rational, and norm-using is adopted. The complexity of using rules as tools to change the structure of commons dilemmas is then discussed, drawing on extensive research on rules in field settings. Viewing all policies as experiments with a probability of failure, recent research on a different form of general organization—that of complex adaptive systems—is applied to the process of changing rules. The last sections examine the capabilities and limits of a series of completely independent resource governance systems and the importance of encouraging the evolution of polycentric governance systems.

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## 1. THE POLICY PUZZLE

Since the influential article by Garrett Hardin (1968), "the tragedy of the commons" has been used as a metaphor for the problems of overuse and degradation of natural resources including the destruction of many fisheries, the overharvesting of timber, and the degradation of forests. Many policy analysts, scholars, and public officials agree with Hardin's conclusion that the participants in a commons dilemma are trapped in an inexorable process from which they cannot extract themselves. External authorities are presumably needed to impose rules and regulations on local users since they will not do this themselves. Viewing resource users as trapped in a tragedy of their own making is consistent with contemporary textbooks on resource economics and the predictions derived from non-cooperative game theory for finitely repeated dilemmas (E. Ostrom et al 1994).

Further, the "scientific management of natural resources" taught to future regulators of natural resources presents fisheries, forests, and water resources as relatively homogeneous units that are closely interrelated across a vast domain. Irrigation systems are interlinked along watersheds of major river systems. Fish and wildlife species tend to migrate over a large range.. This approach, as it has been applied to fisheries management, is described by Acheson et al (1998:391-92).

For those trained in scientific management, it is also an anathema to manage a species over only part of its range. From the view of fisheries scientists and administrators, it is not rational to protect a species in one zone only to have it migrate into another area where it can be taken by other people due to a difference in regulations. As a result, the units to be managed range along hundreds of miles of coast and can only be managed by central governments with jurisdiction over the entire area. Lobsters, for example, extend from Newfoundland to the Carolinas; swordfish migrate from the Caribbean to Newfoundland and Iceland. From the point of view of the National Marine Fisheries Service, it makes sense to have a set of uniform regulations for the entire US coast rather than one for each state, (see Sherman & Laughlin 1992)

Contemporary policy analysts also share a belief in the feasibility of designing close to optimal rules to govern and manage common-pool resources for a large domain utilizing top-down direction. Since common-pool resources are viewed as relatively homogeneous, and interlinked and simple models exist of how they work, officials acting in the public interest are considered capable of devising uniform and effective rules for an entire region. What is needed is to gather reliable, statistical information on key variables, determine what the optimal harvesting pattern should be, divide the harvesting level into quotas, and assign quotas to users. Prescriptions calling for central governments to impose uniform regulations over most natural resources are thus consistent with important bodies of theoretical work, as well as the most advanced scientific approaches to resource policy.

These prescriptions are not, however, supported by extensive research. An extraordinary number of field studies have found that local groups of resource users, sometimes by themselves and sometimes with the assistance of external institutional arrangements, have created a wide diversity of institutional arrangements for coping with common-pool resources where they have not been prevented from doing so by central authorities (McCay & Acheson 1987, Fortmann & Bruce 1988, Berkes 1989, V. Ostrom et al

1993, Netting 1993, Bromley et al 1992, Tang 1992, Blomquist 1992). These empirical studies document successful self-organized resource governance systems in diverse sectors in all parts of the world. Examples also exist of commons dilemmas that have continued unabated, but one conclusion that can firmly be made in light of extensive empirical evidence is that overuse and destruction of common-pool resources is not a determinant and inescapable outcome when multiple users face a commons dilemma. Scholars have begun to identify the conditions of a resource, and of the users of a resource, that are most conducive to local users self-organizing to find solutions to commons dilemmas (see E. Ostrom 1992, 1998b; Baland & Platteau 1996). And, the broad design principles that characterize robust self-organized resource governance systems that have resolved commons dilemmas for long periods of time have been identified (E. Ostrom 1990) and found basically sound by other scholars (Morrow & Hull 1996).

Another important set of findings is that national governmental agencies have been notably unsuccessful in their efforts to design an effective and uniform set of rules to regulate important common-pool resources across a broad domain. Many developing countries nationalized all land and water resources during the 1950s and 1960s. The institutional arrangements that local users had devised to limit entry and use lost their legal standing, but the national governments lacked funds and personnel to monitor the use of these resources effectively. Thus, common-pool resources were converted to a *de jure* government-property regime, but reverted to a *de facto* open-access regime (Arnold 1998, Arnold & Stewart 1991). The incentives of a typical commons dilemma are accentuated since local users have specifically been told that they will not receive any benefits of their adopting a long-term view in their use of the resource. When resources that were previously controlled by local participants have been nationalized, state control has usually proved to be less effective and efficient than control by those directly affected, if not disastrous in its consequences (Curtis 1991, Panayotou and Ashton 1992, Ascher 1995). The harmful effects of nationalizing forests that had earlier been governed by local user-groups have been well documented for Thailand (Feeny 1988), Africa (Shepherd 1992, Thomson 1977, Thomson et al 1992), - Nepal (Arnold & Campbell 1986), and India (Gadgil & Iyer 1989, Jodha 1990, 1996). Similar results have occurred in regard to inshore fisheries taken over by state or national agencies from local control by the inshore fishermen themselves (Cordell & McKean 1992, Cruz 1986, Dasgupta 1982, Higgs 1996, Pinkerton 1989).

Tang (1992) and Lam (1998) have also both found that large-scale government irrigation systems do not tend to perform at the same level as smaller-scale, farmer-managed systems (see also Mehra 1981, Levine 1980, Bromley 1982, Hilton 1992). In a study of over 100 irrigation systems in Nepal, Lam (1998) finds that the cropping intensity and agricultural yield of crudely constructed irrigation systems using mud, rock, timbers, and sticks is significantly higher than the performance of systems built with modern concrete and iron headworks operated by national agencies.

A considerable disjuncture exists between currently accepted policy recommendations based on well-received theories of human behavior in commons dilemmas and evidence from the field (Berkes et al 1989). Field research has generated anomalous and puzzling findings. Instead of being incapacitated to extract themselves from commons dilemmas, when allowed to do so, users frequently self-organize and develop their own rules. Once self-organized, they are able to use resources sustainably for long periods of time. When national governments have taken over full responsibility for regulating the use of forests, fisheries, and irrigation systems, degradation of these resources has been a frequent result. Uniform *de jure* rules are frequently ignored, and overharvesting escalates rather than diminishes.

These findings challenge three of the most important theoretical foundations of contemporary policy analysis. One foundation is the model of the human actor that is used. Resource users are explicitly thought of as norm-free maximizers of immediate gains who will not cooperate to overcome the perverse

incentives of dilemma situations in order to increase their own and others' long-term benefits unless coerced by external authorities. Government officials are implicitly depicted, on the other hand, as seeking the more general public interest and being able to analyze long-term patterns in order to design optimal policies.

A second foundational belief is that designing rules to change the incentives of participants is a relatively simple analytical task best done by objective analysts not intimately related to any specific resource. Analysts view most resources in a particular sector as relatively similar and sufficiently inter-related that they need to be governed by the same set of rules. Third is the view that organization itself requires *central direction*. Consequently, the multitude of self-organized resource governance systems are viewed as mere collections of individual agents each out to maximize their own short-term returns. The groups who have actually organized themselves are invisible to those who cannot imagine organization without rules and regulations issued by a central authority (see, for example, Lansing 1991, Lansing & Kremer 1994).

In this paper, I propose to show that these three foundational assumptions are wrong and a poor foundation for public policy recommendations. To do this, I will first need to define what is meant by a common-pool resource, which is done in the first part of Section 2. In the second part of Section 2, I use the Institutional Analysis and Development (IAD) framework to show how the seven components of an action situation can be used to construct an appropriation dilemma—the central common-pool resource problem identified in most policy texts. To address the adequacy of the model of the human actor used, I summarize the findings from a series of carefully controlled laboratory experiments of appropriation dilemmas in Sections 3 and 4. Given that predictions based on the model of a norm-free, myopic, and maximizing individual are not supported, Section 5 is devoted to the presentation of a closely related but alternative conception of human behavior—applicable to resource users and government officials alike. Humans are viewed as fallible, boundedly rational, and norm using. In complex settings, no one is able to do a complete analysis before actions are taken, but individuals learn from mistakes and are able to craft tools—including rules—to improve the structure of the repetitive situations they face.

In Section 6, I explore the complexity of using rules as tools to change the structure of commons dilemmas. First I describe the seven clusters of rules that affect the components of any action situation, and then describe the specific rules that are used in field settings by resource users and government agencies. An examination of the types of rules used in the field yields several important findings. First, the *number* of rules actually used in field settings is far greater than generally recognized. Second, the *type* of rules is also different. Boundary rules tend to include as co-appropriators of a resource those who are more likely to be trustworthy because they live permanently nearby and have a long-term stake in keeping a resource sustainable. Authority rules define rights and duties that are easy to understand, directly related to sustaining the biophysical structure of the resource, and easy to monitor and enforce. Some rules recommended in the policy literature are not found among the rules used by self-organized systems.

Given the complexity of the process of designing rules to regulate the use of common-pool resources, I argue in Section 7 that all policy proposals must be considered as experiments. No one can possibly know whether a proposed change in rules is among the more optimal rule changes or even whether a rule change will lead to an improvement. All policy experiments have a positive probability of failing. Then, in Section 8, I draw on recent research by John Holland (1995) and colleagues at the Santa Fe Institute to discuss the attributes and mechanisms of a different form of general organization—a complex adaptive system—that is not the result of central direction. Complex adaptive systems cannot be understood if one tries to fit these systems into the image of an organization with a central director.

In Section 9, I then show how the parallel efforts by a large number of local resource users to search out and find local rule configurations may find better rule combinations over the long term while top-down design processes are more limited in their capacities to search and find appropriate rules. All forms of decision making have limits. In Section 10, I discuss the limits of a series of completely independent resource governance systems and the importance of building polycentric governance systems with considerable overlap to combine the strengths of parallel search and design processes with the strengths of larger systems in conflict resolution, acquisition of scientific knowledge, monitoring the performance of local systems, and the regulation of common-pool resources that are more global in their scope. The resulting polycentric governance systems are also not directed by a single center. They, too, are complex adaptive systems requiring policy analysts to change their fundamental views of organization in order to cope more effectively with tragedies of the commons and many of the other problems facing modern societies.

## 2. THE COMPONENTS OF A COMMONS PROBLEM

### *The Definition of a Common-Pool Resource*

A common-pool resource, such as a lake or ocean, an irrigation system, a fishing ground, a forest, the internet, or the stratosphere, is a natural or man-made resource from which it is difficult to exclude or limit users once the resource is provided by nature or produced by humans (E. Ostrom et al 1994). One person's consumption of resource units removes those units from what is available to others. Thus, the trees or fish harvested by one user are no longer available for others. The difficulty of excluding beneficiaries is a characteristic that is shared with public goods, while the subtractability of the resource units is shared with private goods. In this paper, I will focus primarily on renewable natural resources as exemplars of common-pool resources, but the theoretical arguments are relevant to man-made common-pool resources, such as the internet, as well.

When the resource units produced by a common-pool resource have a high value and institutional constraints do not restrict the way resource units are appropriated, individuals face strong incentives to appropriate more and more resource units leading eventually to congestion, overuse, and even the destruction of the resource itself. Because of the difficulty of excluding beneficiaries, the free-rider problem is a potential threat to efforts to reduce appropriation and improve the long-term outcomes achieved from the use of the common-pool resources. If some individuals reduce their appropriation levels, the benefits are shared with others whether they cut back on their appropriation or not. Some individuals may free ride on the costly actions of others unless ways are found to reduce free riding as an attractive strategy. When free riding is a major problem, those who would willingly reduce their own appropriations if others did, are unwilling to make a sacrifice for the benefit of a large number of free riders.

Consequently, one of the important problems facing the joint users of a common-pool resource is known as the "appropriation problem" given the potential incentives in all jointly used common-pool resources for individuals to appropriate more resource units when acting independently than they would if they could find some way of coordinating their appropriation activities. Joint users of a common-pool resource often face many other problems including assignment problems, technological externality problems, provision problems, and maintenance problems (E. Ostrom et al 1994, E. Ostrom & Walker 1997). And, the specific character of each of these problems differs substantially from one resource to the next. In this paper, I focus more on appropriation problems since they are what most policy analysts associate with "the tragedy of the commons."

## *A Baseline Appropriation Situation*

Instead of there being a single model that adequately captures the essential structure of all common-pool resources, there are instead universal components of all situations where individuals interact on a structured and repetitive basis. These components take multiple values and combine to produce an incredible variety of action situations. The structure of any action situation can be analyzed by identifying seven components and how they generate a set of incentives for those involved. The components include:

1. Participants
2. Positions
3. Actions
4. Outcomes
5. Transformation functions linking actions and outcomes
6. Information
7. Payoffs

Basically, one is interested in learning about the number and characteristics of participants in positions who must decide among diverse actions in light of the information they possess about how actions are linked to potential outcomes and the costs and benefits assigned to actions and outcomes (see E. Ostrom et al 1994, ch. 2). While it is possible to identify the component parts, the resulting action situation is a complex system whose structure is derived from the combination of parts. Appropriation situations have many structures depending on the combination of particular attributes of each of these seven components.

In order to understand the process of coping with appropriation problems, we need to start with a static, baseline situation that is as simple as we can specify it without losing crucial aspects of the problems that real appropriators face in the field. Further, we need to start with an "institution free" baseline situation so that we can understand the outcomes predicted and achieved in such a baseline situation and the processes involved in changing the structure by changing rules affecting it. I will outline the baseline appropriation situation that is based on accepted theory and has been used in a large number of laboratory experiments (see E. Ostrom et al 1992, 1994). This institution-free, static, baseline situation is composed of:

1. A set of  $n$  symmetric appropriators who are interested in withdrawing resource units from a common-pool resource.
2. No differentiation exists in the positions these appropriators hold relevant to the common-pool resource. In other words, there is only one position of appropriator.
3. Appropriators must decide how to allocate their time and effort in each time period. Basically, one can think of these appropriators as being "endowed" with a set of assets,  $e$ , that they are free to allocate during each time period to two activities. Each day, for example, appropriators must decide between spending time trying to harvest resource units from the common-pool resource or to use time in their next best opportunity, such as working in a local factory. To simplify the problem, we posit that all appropriators have the same endowment, face the same labor market, and can earn a fixed wage for any time they allocate to working for a factory. Thus, they have to decide how much time to devote to appropriation from the common-pool resource or in their next best opportunity.



4. The actions they take, affect the amount of resource units that can be appropriated from the common-pool resource or wages earned in the labor market.
5. Transformation functions map the actions of all of the appropriators given the biophysical structure of the resource itself onto outcomes. While these functions are frequently stochastic in field settings and affected by many variables in addition to the actions of individuals, we will only consider determinant functions of appropriation actions in the baseline setting. The wage function simply multiplies the amount of time allocated to it by whatever is the standard wage. The appropriation function is a concave function,  $F$ , that depends on the number of assets,  $x_i$ , allocated to appropriation from the common-pool resource. Initially, the sum of individuals' actions,  $\sum x_i$ , generates better outcomes than the safe investment in wage labor. If the appropriators decide to allocate a sufficiently large number of their available assets, the outcome they receive is less than their best alternative. In other words, allocating too many assets to the common-pool resource is counterproductive. Such a function is specified in many resource economics textbooks based on the pathbreaking articles by Scott Gordon (1954) and Anthony Scott (1955).
6. As an initial information condition, we assume that appropriators know the shape of the transformation function and know that they are symmetric in assets and opportunities. Information about outcomes is generated after each decision round is completed.
7. Payoff rules specify the value of the wage rate and the value of the resource units obtained from the common-pool resource. Specifically, the payoff to an appropriator is given by:

$$\begin{aligned}
 & \text{we} && \text{if } x_i = 0 \\
 & w(e - x_i) + (x_i / \sum x_i) F(\sum x_i) && \text{if } x_i > 0.
 \end{aligned} \tag{1}$$

Basically, if appropriators put all of the assets into wage labor, they receive a certain return equal to the amount of their endowment times the wage rate. If appropriators put some of their endowed assets into wage labor and some into the common-pool resource, they get part of their return from wages and the rest from their proportional investment in the common-pool resources times the total output of the common-pool resource as determined by function  $F$ .

#### *Assumptions about Actors*

To explain and predict the outcome of any situation, one needs to specify four key characteristics about the actors who are participating in the situation: (1) the type of preferences held, (2) how information is processed, (3) the formula or heuristic used for making decisions, and (4) the resources brought to the situation. The theory of complete rationality uses the assumptions that (1) individuals have a complete and transitive ordering of preferences over all outcomes that is monotonically related to only their own returns, (2) all relevant information generated by the situation is used in making decisions, (3) actors maximize their own expected returns, and (4) all needed resources to act in this situation are possessed.

The theory of norm-free, complete rationality has proved to be extremely useful in a diversity of circumstances where the institutional arrangements reduce the number of options and complexity of the situation and reward those who maximize expected returns to self and punish those who do not. When such situations are completely specified, clear predictions of equilibrium outcomes can be derived. Behavior in experimental laboratories and in the field closely approximates the predicted equilibrium in simple action

situations where selection pressures retain those who maximize their own expected returns and thin out those who do not.

The theory of norm-free, complete rationality is also useful in a variety of other situations to enable the analyst to undertake a full analysis and predict equilibrium outcomes. If behavior deviates from the predicted outcomes, one has a clear benchmark for knowing how far behavior deviates from that predicted by this theory. We will thus initially use the theory of norm-free, complete rationality and the theory of finitely repeated games to predict what the outcome would be if a set of experimental subjects were to face a fully specified baseline appropriation situation as outlined above. We will later modify this set of assumptions in light of the evidence obtained in the experimental laboratory (and supplemented by field studies).

### *Predicted Outcomes for a Common-Pool Resource in the Laboratory*

Laboratory experiments provide an opportunity to observe how humans behave in situations that are very simple when compared to field settings, but nonetheless, characterize essential common elements of relevant field situations. In the laboratory experiments conducted at Indiana University, we thought it crucial to examine behavior in an appropriation situation with a non-linear transformation function and a sufficient number of players that knowledge of outcomes did not automatically provide information about each player's actions. In this paper, I can only briefly discuss the results of these experiments. All procedures and specifications are thoroughly documented in Ostrom et al (1994) and in journal articles cited therein. In the baseline experiments, we utilized the following equation for the transformation function,  $F$ .

$$23 (\sum x_i) - 25 (\sum x_i)^2 \tag{2}$$

Eight subjects participated in all experiments discussed in this paper and each subject was assigned either 10 or 25 tokens as their endowment in each round of play. Their outside opportunity was valued at \$.05 per token. They earned \$.01 on each outcome unit they received from investing tokens in the common-pool resource. Subjects were informed that they would participate in an experiment that would last no more than two hours. The number of rounds in each experiment varied between 20 and 30 rounds. Instead of asking subjects to pretend they were fishing or harvesting timber, the situation was described as involving a choice between investing in either of two markets having the structure as specified above. In addition to being told the payoff function specifically, subjects were provided with look-up tables that eased their task of determining outcomes depending on their own and others' decisions. All experiments reported on in this paper involved subjects who had prior experience in similar experiments.

With these specifications, the predicted outcome for a finitely repeated game where subjects are not discounting the future is for each subject to invest 8 tokens in the CPR for a total of 64 tokens. The prediction is the same for both endowment levels. At this level of investment, they would each earn \$.66 per round in the 10-token experiments and \$.70 per round in the 25-token experiments (players were paid one-half of their computer returns in the 25-token experiments to keep the payoffs roughly similar). The players could, however, earn considerably more if the total number of tokens invested was 36 tokens, rather than 64 tokens, in the common-pool resource. This optimal level of investment would earn each subject \$.91 per round in the 10-token experiment and \$.83 per round in the 25-token experiment. The baseline experiment is an example of a commons dilemma in which the predicted outcome involves substantial overuse of a common-pool resource, while a much better outcome could be reached if subjects were to lower their joint use.

### 3. BEHAVIOR IN A SPARSE EXPERIMENTAL N-PERSON, REPEATED APPROPRIATION DILEMMA

As documented in Ostrom et al (1994), subjects interacting in baseline experiments substantially overinvested as predicted. Subjects in the 10-token experiments achieved, on average, 37 percent of the maximum available to them while subjects in the 25-token experiments received -3 percent (E. Ostrom et al 1994:116). However, at the individual level, subjects rarely invested 8 tokens, which is the predicted level of investment at equilibrium. Instead, all experiments provided evidence of an unpredicted and strong pulsing pattern in which individuals appear to increase their investments in the common-pool resource until there is a strong reduction in yield, at which time they tend to reduce their investments leading to an increase in yields. The pattern is repeated over time. At an aggregate level, behavior approximates the predicted Nash equilibrium in the 10-token experiments, but is far lower than predicted in the early rounds of the 25-token experiment and only begins to approach the predicted level in later rounds. No game-theoretical explanation exists for the pulsing pattern or the substantial difference between the 10-token and the 25-token experiments.

Subjects explained that they were using several heuristics in response to post-experiment questioning. One of the heuristics was to invest more in the common-pool resource whenever the rate of return on the previous round was above \$.05 (what they could earn in their next best alternative) and less if the return was below \$.05. In the 10-token experiment, some players invested all ten of their tokens whenever the rate of return in the prior round was above \$.05. Equilibrium is really never reached at the individual level. Thus, "each player is continually having to revise his or her response to the current 'anticipated' situation. This strategic turbulence on top of an already complex task increases the chances that a player may not attempt a best-response approach to the task but rather invoke simple rules of thumb.. ." (E. Ostrom et al 1994:121-22).

These laboratory experiments have been replicated by other researchers (Rocco & Warglein 1995) with very similar results. An extremely interesting study was recently completed by Peter Deadman (1997) in which artificial agents were programmed to use a variety of heuristics similar to those used by the human subjects in these experiments and to interact in a simulated environment that exactly replicated the baseline experiments. Deadman found that the specific results obtained in any series of runs depended on the particular heuristic (or mix of heuristics) programmed, but the artificial agents did consistently produce the same kind of pulsing returns and the consistent difference between 10-token and 25-token environments were also observed. Deadman describes his results:

As in CPR experiments, the group performance for the simulation follows an oscillating pattern in which high performance leads to over investment in the CPR and the resultant drop in performance causes a reduction in group-wide investment in the C P R . . . .

Still more interesting is the observation that the simulations perform similarly to subjects in laboratory experiments in terms of average performance over time. At the ten token endowment, the simulations perform near the Nash equilibria over time. At the 25 token endowment, the simulations perform near zero percent of optimum over time. (Deadman 1997:175-76)

Consequently, both human subjects and artificial agents programmed to use heuristics performed in a very similar manner in the baseline environment.

#### 4. STRUCTURAL CHANGE IN THE LABORATORY

In addition to the baseline experiments, we have explored how changes in the rules affect outcomes. Rule changes are operationalized in the set of instructions given to subjects and in the procedures adopted within the experiment. The first structural change is an information rule change. Instead of forbidding all communication among subjects, as in the baseline experiments, subjects are now authorized to communicate with one another in a group setting before returning to their terminals to make their own private decisions. This introduction of an opportunity for "cheap talk," where agreements are not enforced by an external authority, is viewed within the context of non-cooperative game theory as irrelevant. The same outcome is predicted as in the baseline experiment. In a second series of experiments, we changed the authority and payoff rules to allow subjects to sanction one another at a cost to themselves. Since using this option produces a benefit for all at a cost to the individual, the game-theoretic prediction is that no one will choose the costly sanctioning option. Third, we changed the authority rule to allow subjects to covenant with one another to determine their investment levels and to adopt a sanctioning system if they wished. Again, the predicted outcome is the same. In all three of these structurally changed appropriation experiments, however, subjects demonstrate their willingness and ability to search out and adopt better outcomes than those predicted.

##### ***Face-to-Face Communication***

In the repeated communication experiments, subjects made ten rounds of decisions in the context of the baseline appropriation game. At this point, subjects listened to an announcement that told them they would have an open group discussion before each of the continuing rounds of the experiment. The subjects left their terminals and sat in a group facing one another. After each discussion, they returned to their terminals and entered their anonymous decisions. Subjects used face-to-face communication to discuss together what strategy would gain them the best outcomes and to agree on what everyone should invest in the subsequent rounds. After each decision round, they learned as in the baseline experiments what their aggregate investments had been, but not the decisions of individual players. Thus, they learned whether total investments were greater than their agreement. While in many rounds, subjects did exactly as they had promised one another they would do, some defections did occur. If promises were not kept, subjects used this information to castigate the unknown participant who had not kept to their agreement.

This opportunity for repeated face-to-face communication was extremely successful in increasing joint returns in the 10-token experiments where subjects obtained close to 100 percent of the maximum available returns. There were only 19 instances out of 368 total opportunities where a subject invested more in the common-pool resource than agreed upon for a 5 percent defection rate (E. Ostrom et al 1994:154). In the 25-token experiments, subjects also improved their overall performance but the temptation to defect was greater. Subjects in the 25-token baseline experiments had received total returns that were slightly below zero, while in the communication experiments, they obtained on average 62 percent of the maximum available returns (with considerable variation across experiments). The defection rate was 13 percent. Our conclusion in completing an analysis of these experiments was:

Communication discussions went well beyond discovering what investments would generate maximum yields. A striking aspect of the discussion rounds was how rapidly subjects, who had not had an opportunity to establish a well-defined community with strong internal norms, were able to devise their own agreements and verbal punishments for those who broke those agreements. . . . In many cases, statements like "some scumbucket is investing more than we agreed upon" were a sufficient reproach to change defectors' behavior. (E. Ostrom et al 1994:160)

That subjects had internalized norms regarding the importance of keeping promises is evidenced by several of their behaviors. Simply promising to cut back on their investments in the common-pool resource led most subjects to change their investment pattern. Secondly, subjects were indignant about evidence of investment levels higher than that promised and expressed their anger openly. Third, those who broke their promise tended to revert to the promised level after hearing the verbal tongue-lashing of their colleagues.

### ***Sanctioning Experiments***

Participants in field settings are usually able to communicate with one another on a face-to-face basis, at least from time to time, either in formally constituted meetings or at social gatherings. In most field settings, however, participants have also devised a variety of formal or informal ways of sanctioning one another if rules are broken. Engaging in costly monitoring and sanctioning behavior is, however, not consistent with the theory of norm-free, complete rationality (Elster 1989:40-41). Thus, it is important to ascertain whether subjects in a controlled setting would actually pay in order to assess a financial punishment on the behavior of other participants. The short answer to this question is yes.

All sanctioning experiments used the 25-token design since defections were much higher in this design. Subjects played ten rounds of the baseline game modified so that the individual contributions in each round were reported as well as the total outcomes. Subjects were then told that in the subsequent rounds they would have an opportunity to pay a fee in order to impose a fine on the payoffs received by another player. The fees ranged in diverse experiments from \$.05 to \$.20 and the fines from \$. 10 to \$.80. In brief, the finding from this series of experiments is that much more sanctioning occurs than the zero level predicted. Subjects react both to the cost of sanctioning and to the fee/fine relationships. They sanction more when the cost of sanctioning is less and when the ratio of the fine to the fee is higher. Sanctioning is primarily directed at those who invested more in the common pool resource, but a few sanctions appear to be directed by those who had been fined in a form of "blind revenge" against those whose investments were lower than others and were thus suspected of having sanctioned them. In this set of experiments, subjects were able to increase their returns modestly to 39 percent of maximum, but when the costs of fees and fines were subtracted from the total, these gains are wiped out. When subjects were given a single opportunity to communicate prior to the implementation of sanctioning capabilities, they were able to gain an average of 85 percent of the maximum payoffs (69 percent when the costs of the fees and fines were subtracted).

### ***Covenanting Experiments***

In self-organized field settings, participants rarely impose sanctions on one another that have been devised exogenously as the experimenters did in the above sanctioning experiments. Sanctions are much more likely to emerge from an endogenous process of crafting their own rules, including the punishments that should be imposed if these rules are broken. Spending time and effort designing rules creates a public good for all of those involved and is thus a second-level dilemma. Non-cooperative game theory predicts that participants will not undertake such efforts. This is the foundation for the repeated recommendation that rules must be imposed on participants by external authorities who then assume responsibility for monitoring and enforcing these rules. Since self-organized rules are found in many local common-pool resource situations, it does appear that participants frequently do design their own rules contrary to the theoretical prediction. Few scholars are able to witness these processes, however.

Subjects experienced with baseline and sanctioning experiments were recalled and given an opportunity to have a "constitutional convention" in the laboratory to decide whether or not they would like to have access to a sanctioning mechanism like the one described above, how much the fines and fees should be, and on the joint investment strategy that they would like to adopt. All of these groups were endowed with

25 tokens in each round. Four out of six experimental groups adopted a covenant in which they specified the number of tokens they would invest and the level of fines to be imposed. The fines determined by the participants ranged in size from \$.10 to \$1.00. The groups that crafted their own agreements were able to achieve an average of 93 percent of the maximum in the periods after their agreement. And, the defection rate for these experiments was only 4 percent. The two groups that did not agree to their own covenant did not fare as well. They averaged 56 percent of the maximum available returns and faced a defection rate of 42 percent. Consequently, those subjects that used an opportunity to covenant with one another to agree on a joint strategy, choose their own level of fines, received very close to optimal results based entirely on their own promises and their own willingness to monitor and sanction one another when it was occasionally necessary (see Frohlich et al 1987 for similar findings).

## 5. WHAT THEORY OF HUMAN BEHAVIOR IS CONSISTENT WITH EVIDENCE FROM LABORATORY EXPERIMENTS

The appropriation experiments briefly summarized above provide the following picture of behavior in N-person commons-dilemma situations:

1. When individuals are held apart and unable to communicate on a face-to-face basis (or via the type of signalling that is feasible in two-person situations), they overuse a common-pool resource.
2. Individuals use heuristics in dealing with complex problems.
3. Heuristics vary in their capabilities to cope with a changing configuration of actions by other participants.
4. Individuals initially use an opportunity for face-to-face discussions to share their understanding of how their actions affect the joint outcomes and arrive at a common understanding of the best joint strategy available to them.
5. Individuals are willing to promise others, whom they assess as being trustworthy, that they will adopt a joint plan of action. Most individuals keep their promises (in situations where substantial advantage can accrue for breaking the promise).
6. If agreements are broken, individuals become indignant and use verbal chastisements when available. They are also willing to use costly sanctions, and even tend to overuse them, but they do not use grim trigger strategies.
7. When given an opportunity to craft their own rules and sanction non-conformance to these rules, many groups are willing to do so. Through their own efforts, these groups achieve close to optimal results. Those who forego such an opportunity are not able to sustain a high level of performance.

In other words, individuals initially rely on a battery of heuristics in response to complexity. Without communication and agreements on joint strategies, these heuristics lead to overuse. On the other hand, individuals are willing to discuss ways to increase their own and others' payoffs over a sequence of rounds. Many are willing to make contingent promises when others are assessed as trustworthy. A substantial number of individuals, but not all, are trustworthy and reciprocate the trust that has been mutually extended. When behavior not consistent with reciprocity is discovered, individuals are willing to use retribution in a variety of forms but not the form used to predict the possibility of optimal outcomes when these situations are modelled as indefinitely repeated games.

Assuming that individuals have the capability to engage in problem solving to increase long-term payoffs, to make promises, to build reputations for trustworthiness, to reciprocate trustworthiness with trust, and to punish those who are not trustworthy, leads to a different type of policy analysis than assuming that individuals seek their own short-term, narrow interests even when presented with situations where everyone's joint returns could be substantially increased. Using the latter theory leads to the policy advice that rules to reduce overuse must be devised by external authorities and enforceably imposed on local users. This has been the foundation for most policy prescriptions regarding the regulation of common-pool resources during the second half of the twentieth century.

A better foundation is to assume that humans may not be able to analyze all situations fully, but that they will make an effort to solve complex problems through the design of regularized procedures and will be able to draw on inherited capabilities to learn norms of behavior, particularly reciprocity (E. Ostrom 1998a, Bendor 1987). Such a behavioral theory of boundedly rational and norm-using behavior, views all policies as experiments and asks what processes of search and problem solving are more likely to arrive at better experiments. The key problems to be solved are how to ensure that those using a common-pool resource share a similar and relatively accurate view of the problems they need to solve, how to devise rules to which most can contingently agree (Levi 1988), and how to monitor activities sufficiently so that those who break agreements through error or succumbing to the continued temptations that exist in all such situations are sanctioned, and thus trust and reciprocity are supported rather than undermined (Bendor & Mookherjee 1990).

The dilemma never fully disappears, even in the best operating systems. Once an agreement has been reached, however, appropriators are no longer making their decisions in a totally independent manner that is almost guaranteed to lead to overuse. But the temptation to cheat always exists. No amount of monitoring and sanctioning reduces the temptation to zero. Instead of thinking of overcoming or conquering tragedies of the commons, effective governance systems cope better than others with the on-going need to encourage high levels of trust at the same time as needing to monitor actions and sanction rule infractions.

Presenting this difference in a theoretical perspective based on carefully designed laboratory experiments is the first task that I set out to accomplish. Boundedly rational, local users are potentially capable of changing their own rules, enforcing the rules they agree upon, and learning from experience to design better rules. The next task is to show why multiple, boundedly rational, local users are better at designing rules than a single team of boundedly rational officials in a central agency. To do this, we need to draw on research about the type of rules used in the field.

## 6. EXPERIMENTING WITH RULES IN THE FIELD

With this change in perspective, we can think of appropriators trying to understand the biophysical structure of a common-pool resource and how to affect each other's incentives so as to increase the probability of sustainable and more efficient use over the long term. Instead of being given a set of instructions with the transformation function fully specified, they have to explore and discover the biophysical structure of a particular resource that will differ on key parameters from similar resources in the same region. Further, they have to cope with considerable uncertainty related to the weather, complicated growth patterns of biological systems that may at times be chaotic in nature, and external price fluctuations affecting the costs of inputs and value of outcomes (see Wilson et al 1991, 1994). In addition to the physical changes that they can make in the resource, the tools they can use to change the structure of the action situations they face consist of seven clusters of rules that directly affect the components of their own action situations. Specifically, the rules they can change include:

Boundary rules affect the characteristics of the *participants*.

Position rules differentially affect the capabilities and responsibilities of those in *positions*.

Authority rules affect the *actions* that participants in positions may, must, or must not do.

Scope rules affect the *outcomes* that are allowed, mandated, or forbidden.

Aggregation rules affect how individual actions are *transformed* into final outcomes.

Information rules affect the kind of *information* present or absent in a situation.

Payoff rules affect assigned *costs and benefits* to actions and outcomes.

Given the non-linearity and complexity of action situations, it is rarely easy to predict what effect a change in a particular rule will produce. For example, a change in a boundary rule to restrict the entry of appropriators simultaneously reduces the number of individuals who are tempted to break authority rules, but it also reduces the number of individuals who monitor what is happening or contribute funds toward hiring a guard. Thus, the opportunities for rule breaking may increase. Further, the cost of a rule infraction will be spread over a smaller group of appropriators and thus, the harm to any individual may be greater. Assessing the overall effects of a change in boundary rules is a non-trivial analytical task (for examples, see Weissing & Ostrom 1991a,b). Instead of conducting such a complete analysis, appropriators are more apt to use their intuitive understanding of the resource and each other to experiment with different rule changes until they find a combination that seems to work in their setting.

To understand the types of tools that are available to appropriators somewhat better, let us examine in some detail the kind of boundary, authority, payoff, and position rules used in field settings. These four clusters of rules are the major tools used to affect appropriation situations in many common-pool resources, while information, scope, and aggregation rules are utilized to complement changes induced by these four rules.

For the past 14 years, colleagues at or associated with the Workshop in Political Theory and Policy Analysis at Indiana University have studied a very large number of irrigation systems, forests, inshore fisheries, and groundwater basins, as well as other common-pool resources (see Schlager 1990; Tang 1992; Schlager et al 1994; Lam 1998; E. Ostrom 1990, 1996; Gibson et al 1998). We have collected an immense archive of original case studies conducted by many different scholars on all sectors in all parts of the world (Martin 1989/92, Hess 1996, see <http://www.indiana.edu/~workshop>). Using the IAD framework, we developed structured coding forms to help us identify the specific kinds of action situations faced in the field as well as the types of rules that users have evolved over time to try to govern and manage their resource effectively. In order to develop standardized coding forms, we read hundreds of cases describing how local common-pool resources were or were not regulated by a government agency, by the users themselves, or by a non-governmental organization (NGO).

### ***Affecting the Characteristics of Users through Boundary Rules***

The most frequent recommendation concerning boundary rules in the policy literature is to limit the number of persons allowed to appropriate from a common-pool resource so that the level of appropriation is reduced or to require users to obtain a license before harvesting. Boundary rules affect the types of participants with whom other participants will be interacting. If contingent cooperation is perceived to be a



possibility, then one of the most important ways to enhance the likelihood of using reciprocity norms is to increase the proportion of participants who are well known in a community, have a long-term stake in that community, and would find it costly to have their reputation for trustworthiness harmed in that community. Reducing the number of users but opening the resource to strangers willing to pay a license fee, but who lack a long-term interest in the sustainability of a particular resource, may reduce the level of trust and willingness to use reciprocity and thus increase enforcement costs substantially.

As shown in Table 1, we identified 27 boundary rules described by case-study authors as having been used in at least one common-pool resource somewhere in the world (E. Ostrom et al 1989). While some systems use only a single boundary rule, many use two or three of these rules in combination. Boundary rules can be broadly classified in three general groups defining how individuals gain authority to enter and appropriate resource units from a common-pool resource. The first type of boundary rule relates to an individual's citizenship, residency, or membership in a particular organization. Many forestry and fishing user groups require members to have been born in a particular location. A second broad group of rules relates to individual ascribed or acquired personal characteristics. Other user groups may require that appropriation depends on ethnicity, clan, or caste. A third group of boundary rules relates to the relationship of an individual with the resource itself. Using a particular technology or acquiring appropriation rights through an auction or a lottery are examples of this type of rule. About half of the rules relate to the characteristics of the users themselves. The other half involve diverse relationships with the resource.

In a systematic coding of those case studies for which sufficient information existed about rules related to inshore fisheries in many parts of the world, Schlager (1990, 1994) coded 33 user groups out of the 44 groups identified as having at least some rules regarding the use of the resource. All 33 groups depended on a combination of 14 different boundary rules (Schlager 1994:258). None of these groups relied on a single boundary rule. Thirty out of 33 groups (91 percent) limited fishing to those individuals who lived in a nearby community, while 13 groups also required membership in a local organization. Consequently, most inshore fisheries organized by the users themselves restrict fishing to those individuals who are well known to each other, have a relatively long-term time horizon, and are connected to one another in multiple ways (see Taylor 1982, Singleton & Taylor 1992).

After residency, the next most frequent type of rules, used in two-thirds of the organized subgroups, involves the type of technology that a potential fisher must be willing to use. These rules are often criticized by policy analysts, since gear restrictions tend to reduce the "efficiency" of fishing. Gear restrictions have many consequences, however. Used in combination with authority rules that assign fishers using one type of gear to one area of the fishing groups and fishers using another type of gear to a second area, they solve conflicts among non-compatible technologies. Many gear restrictions also place a reduced load on the fishery itself and thus help to sustain longer-term use of the resource.

Other rules were also used. A scattering of groups used ascribed characteristics (age—two groups; ethnicity—three groups; race—five groups). Three types of temporary use rights included government licenses (three groups), lottery (five groups), and registration (four groups). Seven groups required participants to have purchased an asset such as a fishing berth, while three groups required ownership of nearby land. Schlager did not find that any particular boundary rule was correlated with higher performance levels, but she did find that the 33 groups who had at least one boundary rule tended to be able to solve common-pool problems more effectively than the 11 groups who had not crafted boundary rules.

In a closely related study of 43 small- to medium-sized irrigation systems managed by farmers or by government agencies, Tang (1992) found that the variety of rules used in irrigation was smaller than among

inshore fisheries. The single most frequently used boundary rule, used in 32 of the 43 systems (74 percent), was that an irrigator must own land in the service area of an irrigation system (Tang 1992:84-85). All of the government-owned and operated irrigation systems relied on this rule and only this rule. Many of the user-organized systems relied on other rules or land ownership combined with other rules. Among the other rules used were ownership of a proportion of the flow of the resource, membership in a local organization, and a per-use fee. Tang (1992:87) found a strong negative relationship between reliance on land as the *sole* boundary requirement and performance. Over 90 percent of the systems using other boundary rules or a combination of rules including land ownership, were rated positively in the level of maintenance achieved and in the level of rule conformance, while less than 40 percent of those systems relying solely on land ownership were rated at a higher performance level ( $p = .001$ ). Many government systems are designed on paper to serve an area larger than they are actually able to serve when in operation, due to a variety of factors including the need to show as many posited beneficiaries as possible to justify the cost of construction (see Palanisami 1982, Repetto 1986). After construction, authorized irrigators find water to be very scarce and are unwilling to abide by authority rules or contribute to the maintenance of the system.

Thus, many of the rich diversity of boundary rules used by appropriators in the field attempt to ensure that the appropriators will be relating to others who live nearby and have a long-term interest in sustaining the productivity of the resource. One way of coping with the commons is thus changing the composition of who uses a common-pool resource to increase the proportion of participants who have a long-term interest, are more likely to use reciprocity, and who can be trusted. Central governments tend to use a smaller set of rules and some of these may open up a resource to strangers without a longer-term commitment to the resource.

### ***Affecting the Set of Allowable Actions through Authority Rules***

Authority rules are also a major type of rule used to regulate common-pool resources. In the coding manual, we identified a diversity of authority rules used in field settings. Some rules involve a simple formula. Many forest resources, for example, are closed to all forms of harvesting during one portion of the year and open for extraction by all who meet the boundary rules during an open season. Most authority rules, however, have two components. On Table 2, the eight allocation formulas used in the field are shown in the left column. A fisher might be assigned to a fixed location (a fishing spot) or to a fixed rotational schedule, a member of the founding clan may be authorized to cut timber anywhere in a forest, while an irrigator might be assigned to a fixed percentage of the total water available during a season or to a fixed time slot. In addition to the formula used in an authority rule, most rules required a basis for the assignment. For example, a fisher might be assigned to a fixed location based on a number drawn in a lottery, on the purchase of that spot in an auction, or on the basis of his or her historical use. An irrigator might be assigned to a fixed rotation based on the amount of land owned, the amount of water used historically, or the specific location of the irrigator.

If all of the bases were likely to be combined with all of the formula, there would be 112 different authority rules (8 allocation formulas x 14 bases). A further complication is that the rules for one product may differ from those of another product in the same resource. In regard to forest resources, for example, children may be authorized to pick fruit from any tree located in a forest so long as it is for their own consumption, women may be authorized to collect so many headloads of dead wood for domestic firewood and certain plants for making crafts, while *shaman* are the only ones authorized to collect medicinal plants from a particular location in a forest (Fortmann & Bruce 1988). Appropriation rights to fish are frequently related to a specific species. Thus, the exact number of rules that are actually used in the field is difficult to compute since not all bases are used with all formulas, but many rules focus on specific products. A

still further complication is that the rules may regularly change over the course of a year depending on resource conditions.

Schlager (1994:259-60) found that all 33 organized subgroups used one of the five basic formulas in their authority rules. Every user group included in her study assigned fishers to fixed locations using a diversity of bases including technology, lottery, or historical use. Thus, spatial demarcations are a critical variable for inshore fisheries. Nine user groups required fishers to limit their harvest to fish that met a specific size requirement, while seven groups allocated fishers to fishing spots using a rotation system and seven other groups only allowed fishing locations to be used during a specific season. Four groups allocated fishing spots for a particular time period (a fishing day or a fishing season).

An important finding—given the puzzles addressed in this paper—is that the authority rule most frequently recommended by policy analysts (see Anderson 1986, 1992; Copes 1986), is *not* used in any of the coastal fisheries included in Schlager's study. Thus, no attempt was made "by the fishers involved to directly regulate the quantity of fish harvested based on an estimate of the yield. This is particularly surprising given that the most frequently recommended policy prescription made by fishery economists is the use of individual transferable quotas based on estimates on the economically optimal quantity of fish to be harvested over the long run" (Schlager 1994:397). In an independent study of 30 traditional fishery societies, James Wilson and colleagues also noted the surprising absence of quota rules:

All of the rules and practices we found in these 30 societies regulate 'how' fishing is done.. That is, they limit the times fish may be caught, the locations where fishing is allowed, the technology permitted, and the stage of the life cycle during which fish may be taken. None of these societies limits the 'amount' of various species that can be caught. Quotas—the single most important concept and tools of scientific management—is conspicuous by its absence. (Acheson et al 1998:397; see Wilson et al 1994)

Local inshore fishers, when allowed to manage a riparian area, thus use rules that differ substantially from those recommended by advocates of scientific management. Fishers have to know a great deal about the ecology of their inshore region including spawning areas, nursery areas, the migration routes of different species, and seasonable patterns just in order to succeed as fishers. Over time, they learn how "to maintain these critical life-cycle processes with rules controlling technology, fishing locations, and fishing times. Such rules in their view are based on biological reality" (Acheson et al 1998:405).

In the irrigation systems studied by Tang (1992:90-91), three types of authority rules are used most frequently: (1) a fixed time slot is assigned to each irrigator (19 out of the 37 cases for which data is available, and in 10 out of 12 government-owned systems), (2) a fixed order for a rotation system among irrigators (13 cases), and (3) a fixed percentage of the total water available during a period of time (5 cases). Three poorly performing systems with high levels of conflict use no authority rule at all. A variety of bases were used in these rules such as "amount of land held, amount of water needed to cultivate existing crops, number of shares held, location of field, or official discretion" (Tang 1994:233). Farmers also do not use rules that assign a specific quantity of water to irrigators other than in the rare circumstances where they control substantial amounts of water in storage (see Maass & Anderson 1986). Fixed time slot rules allow farmers considerable certainty as to when they will receive water without an equivalent certainty about the quantity of water that will be available in the canal. When the order is based on a share system, simply owning land next to an irrigation system is not enough. A farmer must purchase one or more shares to irrigate for a particular time period. Fixed time allocation systems, which are frequently criticized as inefficient, do economize greatly on the amount of knowledge farmers have to have about the entire system and on monitoring costs. Spooner (1974) and Netting (1974) described long-lived

irrigation systems in Iran and in Switzerland where there was perfect agreement on the order and time allotted to all farmers located on a segment of the system, but no one knew the entire sequence for the system as a whole.

Tang also found that many irrigation systems use different sets of rules depending on the availability of water. During the most abundant season, for example, irrigators may be authorized to take water whenever they need it. During a season when water is moderately available, farmers may use a rotation system where every farmer is authorized to take water for a fixed amount of time during the week based on the amount of land to be irrigated. During scarcity, the irrigation system may employ a special water distributor who is authorized to allocate water to those farmers who are growing crops authorized by the irrigation system and are most in need.

The diversity of rules devised by users greatly exceeds the limited authority rules recommended in textbook treatments of this problem. Appropriators thus cope with the commons by a wide variety of rules affecting the actions available to participants and thus their basic set of strategies. Given this wide diversity of rules, it is particularly noteworthy that rules assigning appropriators a right to a specific quantity of a resource are used so infrequently in inshore fisheries and irrigation systems. (They are used more frequently when allocating forest products where the quantity available, as well as the quantity harvested, are much easier to measure (Agrawal 1994)). To assign an appropriator a specific quantity of a resource unit requires that those making the assignment know the total available units. In water resources where there is storage of water from one season to another and reliable information about the quantity of water is available, such rules are more frequently utilized (Blomquist 1992; Schlager et al 1994).

### ***Affecting Outcomes through Payoff and Position Rules***

One way to reduce or redirect the appropriations made from a common-pool resource is to change payoff rules so as to add a penalty to actions that are prohibited. Many user groups also adopt norms that those who are rule breakers should be socially ostracized or shunned and individual appropriators tend to monitor each other's behavior rather intensively. Three broad types of payoff rules are used extensively in the field: (1) the imposition of a fine, (2) the loss of appropriation rights, and (3) incarceration. The severity of each of these types of sanctions can range from very low to very high and tends to start out on the low end of the scale. Inshore fisheries studied by Schlager relied heavily on shunning and other social norms and less on formal sanctions. Thirty-six of the 43 irrigation systems studied by Tang used one of these three rules and also relied on vigorous monitoring of each other's behavior and shunning of rule breakers. The seven systems that did not self-consciously punish rule infractions were all rated as having poor performance. Fines were most typically used (in 21 cases) and incarceration the least (in only 2 cases). Fines tend to be graduated depending on the seriousness of the infractions and the number of prior infractions. The fines used for a first or second offence tend to be very low.

Passing rules that impose costs is relatively simple. The real difficult task is monitoring behavior to ascertain if rules are being broken. Self-organized fisheries tend to rely on self-monitoring more than the creation of a formal position of guard. Most inshore fishers now use short-wave radios as a routine part of their day-to-day operations allowing a form of instant monitoring to occur. An official of a West Coast Indian tribe reports, for example, that "it is not uncommon to hear messages such as 'Did you see so-and-so flying all that net?' over the short-wave frequency—a clear reference to a violation of specified gear limits" (cited in Singleton 1998:134). Given that most fishers will be listening to their short-wave radio, "such publicity is tantamount to creating a flashing neon sign over the boat of the offender. Such treatment might be preceded or followed by a direct approach to the rule violator, advising him to resolve the

problem. In some tribes, a group of fishermen might delegate themselves to speak to the person" (cited in Singleton 1998:134).

Among self-organizing forest governance systems, creating and supporting a position as guard is frequently essential since resource units are highly valuable and a few hours of stealth can generate substantial illicit income. Monitoring rule conformance among forest users by officially designated and paid guards may make the difference between a resource in good condition and one that has become degraded. In a study of 279 forest *panchayats* in the Kumaon region of India, Agrawal & Yadama (1997) found that the number of months a guard was hired was the most important variable affecting forest conditions. The other variables that affected forest conditions included the number of meetings held by the forest council (a time when infractions are discussed) and the number of residents in the village.

It is evident from the analysis that the capacity of a forest council to monitor and impose sanctions on rule-breakers is paramount to maintaining the forest in good condition. Nor should the presence of a guard be taken simply as a formal mechanism that ensures greater protection. It is also an indication of the informal commitment of the *panchayat* and the village community to protect their forests. Hiring a guard costs money. The funds have to be generated within the village and earmarked for protection of the resource. If there was scant interest in protecting the forest, villagers would have little interest in setting aside the money necessary to hire a guard. (Agrawal & Yadama 1997:455)

Whether irrigation systems create a formal position as guard depends both on the type of governance of the system and on its size. Of the 15 government-owned irrigation systems included in Tang (1992), 12 or 80 percent have established a position of guard. Stealing water was a problem on most government-owned systems, but it was endemic on the three systems without guard. Of the 28 farmer-organized systems, 17 (61 percent) utilize the position of water distributor or guard. Of the 11 farmer-organized systems that do not employ a guard, farmers are vigilant enough in monitoring each other's activities on 5 systems (45 percent) that rule conformance is high. That means, of course, that self-monitoring is not high enough on the other 6 systems to support routine conformance with their own rules. A study by Romana de los Reyes (1980) of 51 communal irrigation systems in the Philippines illustrates the effect of size. Of the 30 systems that are less than 50 hectares, only 6 (20 percent) have established a position as guard; of the 11 systems that serve between 50 to 100 hectares, 5 (45 percent) have established guard; and of the 10 systems over 100 hectares, 7 (70 percent) have created guards. She also found that in a survey of over 600 farmers served by these communal irrigation systems, most farmers also patrol their own canals even when they are patrolled by guards accountable to the farmers for distributing water. Further, the proportion of farmers who report patrolling the canals serving their farms increases to 80 percent on the largest self-organized systems compared to 60 percent on the smallest systems.

Creating the position of guard also requires a change in payoff rules so as to be able to remunerate a guard. Several formulas are used. On government-owned irrigation systems, guards are normally paid a monthly wage that is not dependent on the performance of a system or farmers' satisfaction. In South India, Wade (1994) describes self-organized systems where the water distributor-guard is paid in kind as the harvest is reaped by going to each farmer to collect his share based on the amount of land owned by the farmer. Sengupta (1991:104) describes another system where immediately after appointment, the guards "are taken to the temple for oath taking to remain impartial. With this vow, they break a coconut. They are paid in cash at the rate of Rs 10 per acres . . . per month by the cultivators. The *neerpaichys* themselves collect the money." With such subtle ways of changing the way the payment is made to this position, farmers are able to monitor the monitor more effectively.

Boundary and authority rules also affect how easy or difficult it is to monitor activities and impose sanctions on rule infractions. Closing a forest or an inshore fishery for a substantial amount of time, for example, has multiple impacts. It protects particular plants or fish during critical growing periods and allows the entire system time to regenerate without disturbance. Further, during the closed season, rule infractions are highly obvious to anyone as any appropriator in the resource is almost certainly breaking the rules. Similarly, requiring appropriators to use a particular technology may reduce the pressure on the resource, help to solve conflicts among users of incompatible technologies, and also make it very easy to ascertain if rules are being followed. Many irrigation systems set up rotation systems so that only two persons need to monitor actions at any one time and thus keep monitoring costs lower than they would otherwise be. Changing payoff rules is the most direct way of coping with commons dilemmas. In many instances, dilemma games can be transformed into assurance games—a much easier situation to solve.

### ***Affecting Outcomes through Changes in Information, Scope, and Aggregation Rules***

These rules tend to be used in ways that complement changes in boundary, authority, payoff and position rules. Individual systems vary radically in regard to the mandatory information that they require. Many smaller and informal systems rely entirely on a voluntary exchange of information and on mutual monitoring. Where resource units are very valuable and the size of the group is larger, more and more requirements are added regarding the information that must be kept by appropriators or their officials. Scope rules are used to limit harvesting activities in some regions that are being treated as refugia. By not allowing any appropriation from these locations, the regenerative capacity of a system can be enhanced. Aggregation rules are used extensively in collective-choice processes and less extensively in operational settings, but one aggregation rule that is found in diverse systems is a requirement that harvesting activities be done in teams. This increases the opportunity for mutual monitoring and reduces the need to hire special guards.

It is important to note that we have not yet found any *particular* rules to have a statistically positive relationship to performance. The absence of any boundary or any authority rules *is* consistently associated with poor performance. Relying on only a single type of rule for an entire set of common-pool resources is also negatively related. As reported above, self-organized irrigation systems do tend on average to have performance levels higher than government-organized systems controlling for physical terrain but this increased performance level is not due to any specific rules or set of rules that we have yet been able to identify.

## 7. POLICIES AS EXPERIMENTS

### ***The Daunting Search for Better Rules***

It should now be obvious that the search for rules that improve the outcomes obtained in commons dilemmas is an incredibly complex task involving a potentially infinite combination of specific rules that could be adopted. To ascertain whether one has found an optimal set of rules to improve the outcomes achieved in a single situation, one would need to analyze how diverse rules affect each of the seven components of such a situation and as a result, the likely effect of a reformed structure on incentives, strategies, and outcomes. Since there are multiple rules that affect each of the seven components, conducting such an analysis would be an incredibly time and resource-consuming process. For example, if only five changes in rules per component were considered, there would be  $5^7$  or 75,525 different situations to analyze. This is a gross simplification, however, since some of the important rules used in field settings include more than 25 rules (in the case of boundary rules) and even over 100 variants (in the case of authority rules). Further, how these changes affect the outcomes achieved in a particular location depends

on the biophysical characteristics of that location and the type of community relationships that already exist. No set of policy analysts (or even all of the game theorists in the world today) could ever have sufficient time or resources to analyze over 75,000 combinations of rule changes and resulting situations, let alone all of the variance in these situations due to biophysical differences.

### ***Experimenting with Rule Changes***

Instead of assuming that designing rules that approach optimality, or even improve performance, is a relatively simple analytical task that can be undertaken by distant, objective analysts, we need to understand the policy design process as involving an effort to tinker with a large number of component parts (see Jacob 1977). Those who tinker with any tools—including rules—are trying to find combinations that work together more effectively than other combinations. Policy changes are experiments based on more or less informed expectations about potential outcomes and the distribution of these outcomes for participants across time and space (Campbell 1969, 1975). Whenever individuals agree to add a rule, change a rule, or adopt someone else's proposed rule set, they are conducting a policy experiment. Further, the complexity of the ever-changing biophysical world combined with the complexity of rule systems means that any proposed rule change faces a non-trivial probability of error.

When there is only a single governing authority, policymakers have to experiment simultaneously with *all* of the common-pool resources within their jurisdiction with each policy change. And, once a change has been made and implemented, further changes will not be made rapidly. The process of experimentation will usually be slow, and information about results may be contradictory and difficult to interpret. Thus, an experiment that is based on erroneous data about one key structural variable or one false assumption about how actors will react, can lead to a very large disaster (see Wilson et al forthcoming). In any design process where there is substantial probability of error, having redundant teams of designers has repeatedly been shown to have considerable advantage (see Landau 1969, 1973; Bendor 1985).

- For example, let us imagine a series of inshore fisheries located along the coast of a region and posit that every policy change has a probability of failure of 1/10. If the region were regulated by a single governing agency, one out of ten policy changes would be failures for the entire region. If designing rules were delegated to three genuinely independent authorities, on the other hand, each of these authorities would still face a failure rate of one out of ten. The probability that a failure would simultaneously occur along the entire coast, however, would be reduced from 1/10 to  $1/10^3$  or 1/1000. On a coast with many more relatively separable inshore fisheries, the likelihood of a coastal-wide failure is reduced still more. Of course, the failure rate for such design tasks can itself not be known, but the positive effect of parallel, redundant design teams each trying to find the best combination of rules does not depend on any particular error rate. The important point is: If the systems are relatively separable, allocating responsibility for experimenting with rules will not avoid failure, but will drastically reduce the probability of immense failures for an entire region.

## 8. SELF-ORGANIZED RESOURCE GOVERNANCE SYSTEMS AS COMPLEX ADAPTIVE SYSTEMS

As discussed in the introduction, the very concept of ***organization*** is closely tied for many scholars to the presence of a central director who has designed a system to operate in a particular way. Consequently, the mechanisms used by organized systems that are not centrally directed are not well understood in many cases. Many self-organized resource governance systems are invisible to the officials of their own country or those from donor agencies. A classic example of this occurred in the Chitwan valley of Nepal several years ago when an Asian Development Bank team of irrigation engineers recommended a very large loan to

build a dam across the Rapti River to enable the farmers there to irrigate their crops. What the engineering design team did not see was 85 farmer-managed irrigation systems that already existed in the valley and had achieved relatively high performance. Most farmers in the Chitwan valley already obtained three irrigated crops a year as a result of their participation in the activities of these irrigation systems (see Benjamin et al 1994). Similarly, the Nepal Department of Irrigation did not even report the area of land irrigated by farmer-managed irrigation systems in national statistics until very recently.

In contrast to forms of organization that are the result of central direction, most self-organized groups—including the types of locally organized fisheries, forests, grazing areas, and irrigation systems discussed in this paper—are better viewed as complex adaptive systems. Complex adaptive systems are composed of a large number of active elements whose rich patterns of interactions produce emergent properties that are not easy to predict by analyzing the separate parts of a system. Holland (1995:10) views complex adaptive systems as "systems composed of interacting agents described in terms of rules. These agents adapt by changing their rules as experience accumulates." Complex adaptive systems "exhibit coherence under change, via conditional action and anticipation, and they do so without central direction" (Holland 1995:38-39). Holland points out that complex adaptive systems differ from physical systems that are not adaptive and that have been the foci of most scientific effort. It is the physical sciences that have been the model for many aspects of contemporary social science. Thus, the concepts needed to understand the adaptivity of systems are not yet well developed by social scientists.

### ***Properties and Mechanisms of Complex Adaptive Systems***

No general theory of complex adaptive systems yet exists to provide a coherent explanation for processes shared by all complex adaptive systems. Biologists have studied many different adaptive systems but within separate fields of biology. Thus, even biologists have not recognized some of the similarities of structures and processes that characterize the central nervous system, the immune system, and the evolution of species. Recent work at the Sante Fe Institute has begun to identify central attributes, mechanisms, and processes used by all complex adaptive systems including both biological systems as well as markets and other social systems that are not centrally directed (Anderson et al 1988).

It appears that complex adaptive systems all share four basic properties: non-linearity, flows, diversity, and aggregation. The first three properties are self-evident and clearly characterize the types of self-organized resource governance systems discussed in this paper. **Aggregation** refers to the "emergence of complex larger-scale behavior from the aggregate interactions of less complex agents" (Holland 1995:11). For example, many irrigation systems are divided into several tiers and multiple units at each of these tiers. All of the farmers on a field channel are responsible for distributing the water to this small channel as well as keeping it in good repair. All farmers whose field channels are served by a branch canal may send a representative to a branch canal organization that focuses its attention on the distribution of water among all branches and on the maintenance of the distribution canals. The branch canal organization may send a representative to a central committee who is responsible for the headworks that divert the water from a river into the system in the first place. The rules used on one branch canal or one field channel may be quite different than on others. There is no single center of authority for these systems that makes all relevant decisions on how to get water from the river to a farmer's field, but in many farmer-organized systems the water is distributed in an organized fashion and all of the waterworks are maintained as a result of the aggregation of decisions and actions at multiple levels (see Yoder 1994; E. Ostrom 1992; Coward 1979, 1985; Wade 1988).

In addition to these four attributes, complex adaptive systems also use three mechanisms that are key to the adaptive process itself. These include the use of tags, internal models, building blocks.



THE USE OF TAGS. Tagging is a universal mechanism for boundary formation and aggregation of units in complex adaptive systems. "Tags are a pervasive feature of [complex adaptive systems] because they facilitate selective interactions. They allow agents to select among agents or objects that would otherwise be indistinguishable" (Holland 1995:14). All of the types of boundary rules shown in Table 1 involve the specification of the tags that will be used to determine who is authorized to be a co-appropriator from a common-pool resource. Residency, prior membership, and personal characteristics are attributes that already exist that are easy to use as boundary tags. Boundary rules that focus on an individual's relationship with a resource are acquired specifically related to that resource. Local governance systems rely heavily on tags that identify individuals who are already known to each other, who have a long-term stake in the sustainability of a resource, who have an incentive to build a reputation for being trustworthy, and who are thus likely to extend reciprocity rather than recalcitrance in dealing with joint problems.

Tags are also used extensively to mark locations in a resource, to warn rule infractors, and even to mark individual organisms that need to be treated in a special way. An example of the latter occurs along the Maine coast where it is forbidden to harvest berried lobsters (those with eggs). Such lobsters are V-notched and returned back to the sea (Acheson 1988, 1989). Any other fisherman who captures a V-notched lobster is also supposed to return it to the sea. Maine lobstermen warn someone who has put a lobster trap in the wrong place that their rule infraction has been observed by tying a rope on the trap in a noticeable location so that the fisher knows that their infraction has been noticed. If a fisher ignores this initial warning, their lobster traps themselves are likely to be destroyed the next time they are noticed in the wrong location.

INTERNAL MODELS. The appropriators from a common-pool resource build internal models of the resource, the relationships among the components of the resource, and frequently where their own actions are positively or negatively related to one another and the resource. Among the shared lore for most fishing villages is a clear understanding of where fish breed, where young fish tend to cluster, the length of time it takes for fish to be mature and reproduce, the migration patterns of fish, the food chain in a location, etc. Many inshore fishers develop their own maps of all of the fishing spots in their grounds (see, for example, Berkes 1986). In an effort to reduce the interference of one boat with another boat's fishing, these are frequently defined so that if all "spots" are filled, all boats are still able to have a good chance to catch fish. These maps are then used in a variety of allocation rules that specify how any particular boat is assigned to a particular fishing spot. Users of forests also map their forests and may create refugia—sometimes as sacred forests—for sections of a forest that are particularly rich in biodiversity. By not harvesting from these refugia, they serve as a source of regeneration to other nearby locations that are disturbed through harvesting. Similarly, farmers who manage their own irrigation systems have clear mental (and frequently, paper) maps of these physical systems. These system models are called upon when allocating maintenance responsibilities so that their more vulnerable locations are assigned more time and resources than locations that are stable without much maintenance.

BUILDING BLOCKS. Building blocks are ways of breaking down complex processes into small chunks that can be used in multiple ways and combined and re-combined repeatedly and at diverse levels. Once an authority rule that allocates resource units on some basis is determined, for example, using the same basis again to allocate responsibility for maintenance work is considered to be a fair allocation of benefits and costs in many cultures and is relatively easy to remember. On the large Chhattis Mauja farmer-organized system in Nepal, for example, water was originally allocated by the land area served. In the 1950s, the formula used for maintenance work was that each branch canal was responsible to send one person to work on the main canal for each 17 hectares of area it irrigated. "The term used for a person-day of labor for canal maintenance was *kulara*. Since the share of water a branch canal is entitled to receive is the same as the resource mobilization requirement, water allocation is now also referred to as 'so many *kulara* of

water" (Yoder 1991:7). As the system has grown, the total number of *kularas* has now been set at 177 shared among 44 branch canals. Voting rights are now also set in terms of *kularas*. "Therefore, a branch canal with five *kulara* was entitled to 5/177 of the water in the main canal, responsible to supply 5/177 of the resources mobilized for the irrigation, and had five of the total 177 votes in all important decisions" (Yoder 1991:7).

### ***Changing Rules as an Adaptive Process***

Given the logic of combinatorics, it is impossible—as we showed above—to conduct a complete analysis of the expected performance of all of the potential rule changes that could be made by the individuals served by a self-organized resource governance system trying to improve its performance. A similar impossibility also exists for many biological systems. Let us explore these similarities.

Self-organizing resource governance systems have two structures that are somewhat parallel in their function to the concepts of a genotype and a phenotype in biology. Phenotypic structures characterize an expressed organism—how bones, organs, and muscles develop, relate, and function in an organism in a particular environment. The components of an action situation characterize an expressed situation—how the number of participants, the information available, and their opportunities and costs create incentives, and how incentives lead to types of outcomes in a particular environment. The genotypic structure characterizes the set of instructions encoded in DNA to produce an organism with a particular phenotypic structure. A rule configuration is a set of instructions of how to produce the structure of relationships among individuals in an action situation that is also affected by the biophysical world and the kind of community or culture in which an action situation is located.

The evolution of social systems does not follow the same mechanisms as the evolution of species (Boyd and Richerson 1985, Campbell 1975, Nelson and Winter 1982). As an evolutionary process, of course, there must be the generation of new alternatives, selection among new and old combinations of structural attributes, and retention of those combinations of attributes that are successful in a particular environment. In evolving biological systems, genotypic structures are changed through mechanisms such as crossover and mutation and the distribution of particular types of instructions depends on the survival rate of the phenotypes they produce in given environments. Instead of blind variation, however, human agents do try to use reason and persuasion in their efforts to try to devise better rules, but the process of choice always involves experimentation. Self-organized resource governance systems use many types of decision rules to make collective choices ranging from deferring to the judgment of one person or elders, to using majority voting, to relying on unanimity (E. Ostrom, 1998b). The subject of what collective-choice rules are better for coping with tragedies of the commons is itself an entire paper (or book) and will not be discussed here. All I can indicate here is that in our various efforts to explore how rules affect performance, we have not yet found a strong statistical correlation between a particular form of collective choice at a resource governance system level and the sustainability and efficiency of self-organized resource governance systems. Collective-choice rules obviously make a substantial difference in the distribution of benefits to participants.

So, let us explore a little more the relationship between rule configurations and action situations. In Table 3, the left-hand column lists a small subset of the rules typically found in the field. A "1" has been entered in a cell of a column to indicate when a specific rule is in use and a "0" has been entered when the rule is not in use. (One might also use the deontic operators, F = Forbidden, O = Obligatory, and P = Permitted rather than this simple on-off demarcation; see Crawford & Ostrom 1995). Thus, the eight columns represent the simplified rule configurations for eight different appropriation situations.

Appropriation Situation A would be characterized as one where the participants are required to live in a local community, to use fixed locations on a rotation system, but there are no formal sanctions used or guards hired to monitor conformance to the entry rules and rotation system. Further, no records are kept, there are no refugia, and appropriators can work individually or in teams. In contrast, Appropriation Situation C creates a refugia where no appropriation may be undertaken, and does not allocate the remaining space to individual appropriators. In C, appropriators also need to live in the local area and they do face fines if a fellow appropriator notices that they have appropriated from the refugia. While a guard is not created, records are kept of any infractions noted through the mutual monitoring process. If there is a very good breeding and nursery area in this fishery, and it can be well demarked so that it is obvious if someone has ventured into the refugia by error (or by intent), a rule system that does not limit fishing in any other way may be a very effective system for protecting the regenerative capabilities of a fishery. It is certainly less expensive than naming specific fishing spots, making an allocation of each fishing team to particular spots, and enforcing a more complicated rule system.

Appropriation Situation H utilizes a much fuller array of rules. Appropriators must belong to a local cooperative, even though they do not have to live in the local community. A refugia has been created and a system for allocating time in which to conduct appropriation, but this is not spatially defined with the exception of the forbidden area of the refugia. Payoff rules have been modified so that there are both fines for infractions as well as the possibility of losing rights to appropriate if infractions are substantial. Records of infractions and of the time when someone appropriates are required, and individuals are constrained to working in teams rather than being allowed to appropriate as individuals.

Whether any or all of these rule configurations created situations that enabled the participants to appropriate from their resource in a sustainable and efficient manner cannot be ascertained from simply learning about the rules alone. Whether a set of rules enhances performance depends on the structure of the biophysical system itself. Each of these rule configurations creates a very interesting action situation; and if enough information were known about the structure of the environment, it would be possible to model each of these appropriation situations as a game (see Gardner & Ostrom 1991; Weissing & Ostrom 1991b, 1993). Whether the strategy of creating a refugia, as in C and H, works better than the allocation of appropriation locations as in A, depends on how large the refugia is, how rapidly and extensively regeneration from the refugia spreads through the rest of the resource, and how well appropriators understand each of these systems and try to make them work. All three rule systems are likely to work well in some locations and poorly in others.

With this form of representation, however, we can begin to see how experimentation with rules may be similar to changes in similar structures affecting other types of complex adaptive systems. Most systems are likely to start with one or two very simple rules. An obvious first candidate is to use tags to close the boundary to outsiders so that the likelihood of contingent cooperation and conformance to agreements will be enhanced. By only changing a few rules at the beginning, everyone can come to understand those rules while they are evaluating how they work. A second obvious candidate is to use the shared model of the environment built up through years of interaction in an environment to refine where appropriation should be undertaken and when. Space and time are obvious candidates for allocating access to resources in a manner that is relatively low cost to sustain. If the community is small enough and shares common norms at a high enough level, creating formal sanctions, guards, records, and other rules may not be necessary. Thus, one can imagine a process where a rule configuration of mostly zeros slowly converts over time to one with a scattering of ones and potentially to a rule configuration with many rules.

Changes in specific rules may come about through accident (forgetting or innovating on the spot) or through specific collective-choice processes where considerable time and effort is devoted to considering

why performance needs to be enhanced and which rules might be changed. Since many appropriators will have experience with more than one product, rules tried out in regard to one product may be tried in regard to others if they were successful. Migration of individuals into a community brings individuals with repertoires of different rules used in other locations. Commerce with other groups lets appropriators see and learn about other groups who may be doing better (or worse) than they in regulating a sustainable and efficient resource system. Thus, a self-organized resource governance system with a higher level of in-migration or greater communication with other localities is more likely to adapt and change rules over time than one where few new ideas concerning how to use rules as tools are brought into the system. Trial and error processes may give relatively rapid feedback about rules that obviously do not work in a particular environment, but this is not always the case when the effect of human action on the environment has a long time-delay. If all self-organized resource governance systems are totally independent and there is no communication among them, then each has to learn through its own trial and error process. Many will find that rules that they have tried do not work. Some will fail entirely.

The rate of change will differ among self-organized resource governance systems. As with all learning theories, the rate of change is an important variable affecting performance over time. If change occurs too rapidly, little is learned from each experiment before another experiment is launched. Respect for tradition and even religious mystification has been used to increase the retention of rules considered by at least some participants as being better working. If the heavy hand of tradition is, however, too heavy and squelches innovation, a system that may have been well adapted to a past environment may find itself faltering as external changes occur without internal changes also occurring.

In future work, I plan to explore these processes more specifically. They can, however, only be mentioned briefly in this paper since I have one major task left to complete. Thus, I turn to this final task in the next section.

## 9. THE ADVANTAGES AND LIMITS OF PARALLEL SETS OF LOCAL USERS IN POLICY EXPERIMENTS

The last major task to be undertaken in this paper is to discuss why a series of relatively autonomous, self-organized, resource governance systems may do a better job in policy experimentation than a single central authority. In this section, I will discuss the advantages and limits of a fully decentralized system where all responsibility for making decisions related to smaller-scale common-pool resources is localized. In the last section, I will discuss why a polycentric governance system involving higher levels of government as well as local systems is better able to cope more effectively with tragedies of the commons.

Among the advantages of authorizing the users of smaller-scale common-pool resources to adopt policies regulating the use of these resources are:

- Local knowledge. Appropriators who have lived and appropriated from a resource system over a long period of time have developed relatively accurate mental models of how the biophysical system itself operates, since the very success of their appropriation efforts depends on such knowledge. They also know others living in the area well and what norms of behavior are considered appropriate.
- Inclusion of trustworthy participants. Appropriators can devise rules that increase the probability that others are trustworthy and will use reciprocity. This lowers the cost of relying entirely on formal sanctions and paying for extensive guarding.

- Reliance on disaggregated knowledge. Feedback about how the resource system responds to changes in actions of appropriators is provided in a disaggregated way. Fishers are quite aware, for example, if the size and species distribution of their catch is changing over time. Irrigators learn whether a particular rotation system allows most farmers to grow the crops they most prefer by examining the resulting productivity of specific fields.
- Better adapted rules. Given the above, appropriators are more likely to craft rules that are better adapted to each of the local common-pool resources than any general system of rules.
- Lower enforcement costs. Since local appropriators have to bear the cost of monitoring, they are apt to craft rules that make infractions highly obvious so that monitoring costs are lower. Further, by creating rules that are seen as legitimate, rule conformance will tend to be higher.
- Redundancy. The probability of failure throughout a large region is greatly reduced by the establishment of parallel systems of rule making, interpretation, and enforcement.

There are, of course, limits to all ways of organizing the governance of common-pool resources. Among the limits of a highly decentralized system are:

- Some appropriators will not organize. While the evidence from the field is that many local appropriators do invest considerable time and energy into their own regulatory efforts, other groups of appropriators do not do so. There appear to be many reasons for why some groups do not organize including the presence of low-cost alternative sources of income and thus a reduced dependency on the resource, considerable conflict among appropriators along multiple dimensions, lack of leadership, and fear of having their efforts overturned by outside authorities.
- Some self-organized efforts will fail. Given the complexity of the task involved in designing rules, some groups will select combinations of rules that generate failure instead of success. They may be unable to adapt rapidly enough to avoid the collapse of a resource system.
- Local tyrannies. Not all self-organized resource governance systems will be organized democratically or rely on the input of most appropriators. Some will be dominated by a local leader or a power elite who only change rules that they think will advantage them still further. This problem is accentuated in locations where the cost of exit is particularly high and reduced where appropriators can leave when local decision makers are not responsible to a wide set of interests.
- Stagnation. Where local ecological systems are characterized by considerable variance, experimentation can produce severe and unexpected results leading appropriators to cling to systems that have worked relatively well in the past and stop innovating long before they have developed rules likely to lead to better outcomes.
- Inappropriate discrimination. The use of identity tags is frequently an essential method for increasing the level of trust and rule conformance. Tags based on ascribed characteristics can, however, be the basis of excluding some individuals from access to sources of productive endeavor that has nothing to do with their trustworthiness.
- Limited access to scientific information. While time and place information may be extensively developed and used, local groups may not have access to scientific knowledge concerning the type of resource system involved.

- Conflict among appropriators. Without access to an external set of conflict-resolution mechanisms, conflict within and across common-pool resource systems can escalate and provoke physical violence. Two or more groups may claim the same territory and may continue to make raids on one another over a very long period of time.
- Inability to cope with larger-scale common-pool resources. Without access to some larger-scale jurisdiction, local appropriators may have substantial difficulties regulating only a part of a larger-scale common-pool resource. They may not be able to exclude others who refused to abide by the rules that a local group would prefer to use. Given this, local appropriators have no incentives to restrict their own use and watch others take away all of the valued resource units that they have not appropriated.

## 10. THE CAPABILITIES OF POLYCENTRIC SYSTEMS IN COPING WITH TRAGEDIES OF THE COMMONS

Many of the capabilities of a parallel adaptive system can be retained in a polycentric governance system. By polycentric, I mean a system where citizens are able to organize not just one but multiple governing authorities at differing scales (see V. Ostrom et al 1961; V. Ostrom 1987, 1991, 1997). Each unit may exercise considerable independence to make and enforce rules within a circumscribed scope of authority for a specified geographical area. In a polycentric system, some units are general-purpose governments while others may be highly specialized. Self-organized resource governance systems, in such a system, may be special districts, private associations, or parts of a local government. These are nested in several levels of general-purpose governments that also provide civil, equity, as well as criminal courts.

In a polycentric system, the users of each common-pool resource would have some authority to make at least some of the rules related to how that particular resource will be utilized, and thus would achieve most of the advantages of utilizing local knowledge, and the redundancy and rapidity of a trial and error learning process. On the other hand, problems associated with local tyrannies and inappropriate discrimination can be addressed in larger, general-purpose governmental units who are responsible for protecting the rights of all citizens and for the oversight of appropriate exercises of authority within smaller units of government. It is also possible to make a more effective blend of scientific information with local knowledge where major universities and research stations are located in larger units but have a responsibility to relate recent scientific findings to multiple smaller units within their region. Because polycentric systems have overlapping units, information about what has worked well in one setting can be transmitted to others who may try it out in their settings. Associations of local, resource governance units can be encouraged to speed up the exchange of information about relevant local conditions and about policy experiments that have proved particularly successful. And, when small systems fail, there are larger systems to call upon—and vice versa.

Polycentric systems are themselves complex, adaptive systems without one central authority dominating all of the others. Thus, there is no guarantee that such systems will find the optimal combination of rules at diverse levels that are optimal for any particular environment. In fact, one should expect that all governance systems will be operating at less than optimal levels given the immense difficulty of fine-tuning any very complex, multitiered system.

In the United States, there are many examples of dynamic, polycentric resource governance systems where there is strong evidence of high performance. One example is the Maine lobster fishery, which is noteworthy because of the long-term, complementary roles adopted by both local and state governance

systems. Maine is organized into riparian territories along most of the coast. Boundary rules and many of the day-to-day fishing regulations are organized by harbor gangs (Acheson 1988).

In order to go fishing at all, one must become a member of a 'harbor gang,' the group of fishermen who go lobstering from a single harbor. Once one has gained admittance into such a group, one can only set traps in the traditional territory of that particular harbor gang. Members of harbor gangs are expected to obey the rules of their gang concerning fishing practices, which vary somewhat from one part of the coast to another. In all areas a person who gains a reputation for molesting others' gear or for violating conservation laws will be severely sanctioned. Incursions into the territory of one gang by fishers from another are ordinarily punished by surreptitious destruction of lobster gear. There is strong statistical evidence that the territorial system, which operates to limit the number of fishers exploiting lobsters in each territory, helps to conserve the lobster resource. (Acheson et al 1998:400)

At the same time, the state of Maine has long established formal laws that protect the breeding stock and increase the likelihood that regeneration rates will be high. "At present, the most important conservation laws are minimum and maximum size measures, a prohibition against catching lobsters with eggs, and a law to prohibit the taking of lobsters which once had eggs and were marked—i.e. the 'V-notch' law" (Acheson et al 1998:400). Neither the state nor any of the harbor gangs has tried to limit the quantity of lobster captured. The state does not make any effort to limit the number of fishers since this is already done at a local level. However, the state has been willing to intercede when issues exceed the scope of control of local gangs. In the late 1920s, for example, when lobster stocks were at very low levels and many local areas appear to have had substantial compliance problems, the state took a number of steps—including threats to close the fishery—that supported informal local enforcement efforts. By the late 1930s, compliance problems were largely resolved and stocks had rebounded (although it can't be shown that these two results are related, just correlated).

Recently, in response to changes that were breaking down the harbor gang system, the state has formalized the system by dividing the state into zones with democratically elected councils. Each council has been given authority over rules that have principally local impacts—trap limits, days and times fished, etc. Interestingly, the formalization of local zones was followed, almost immediately, by the creation of an informal council of councils to address problems at a greater than local scale. It is expected the council of councils will be formalized soon (Wilson 1997).

Today the state needs only about six patrol officers on the water to police the activities of 6,800 lobstermen, all the other fisheries, and coastal environmental laws. During the 1990s, the fishery has been growing substantially with increased yields (Acheson 1993). At the same time, there is strong evidence that the number of reproductive age females in the Maine waters is very large and that the recruitment levels will continue at a high level.

The system of co-management of the Pacific salmon fisheries in the state of Washington is another noteworthy example of a recently evolved polycentric system that appears to be working much better than an earlier system that was dominated primarily by State and Federal agencies (see Singleton 1998). The change in the system came as a result of a major court decision in the mid-1970s that the Indian tribes who had signed treaties more than a century before, had protected rights to 50 percent of the fish that passed through the normal fishing areas of the tribes. This has required the state to develop a "co-management" system that involves both the state of Washington and the 21 Indian tribes in diverse policy roles related to salmon. This is a large, transboundary resource utilized by major commercial firms as well as by the Indian tribes. Having the state strongly involved means that it is "safe" for any local group to agree to follow strong conservation practices because they know that other local groups are also involved in the

same conservation practices. At the same time, the earlier centrally regulated system had focused on aggregations of species and spent little time on the fresh-water habitats that are essential to maintain the viability of salmon fisheries over the long term. Individual tribal authorities have concentrated their attention on the specific stocks and how to manage these better. Co-management of migrating fishery stocks has also been evaluated as successful in British Columbia and other locations (Pinkerton 1989, Poffenberger & McGean 1996). Alcorn & Toledo (1998) stress the complementary institutional systems at the national level in Mexico, supportive of *ejidos* and *comunidades* at a local level, as generating a more sustainable governance system than exists in similar ecological conditions.

Coping with potential tragedies of the commons is never easy and never finished. Now that we know that those dependant on these resources are not forever trapped in situations that will only get worse over time, we need to recognize that governance is frequently an adaptive process involving multiple actors at diverse levels. Such systems look terribly messy and hard to understand. The scholars' love of tidiness needs to be resisted. Instead, we need to develop better theories of complex adaptive systems, particularly those that have proved themselves able to utilize renewable natural resources sustainably over time.



## ***Literature Cited***

- Acheson JM. 1988. ***The Lobster Gangs of Maine***. Hanover, NH: New England Univ. Press
- Acheson JM. 1989. Management of common-property resources. In ***Economic Anthropology***, ed. S Plattner, 351-78. Stanford: Stanford Univ. Press
- Acheson JM. 1993. Capturing the commons: Legal and illegal strategies. In ***The Political Economy of Customs and Culture: Informal Solutions to the Commons Problem***, ed. TL Anderson, RT Simmons, 69-83. Lanham, MD: Rowman & Littlefield
- Acheson JM, Wilson JA, Steneck RS. 1998. Managing chaotic fisheries. In ***Linking Social and Ecological Systems. Management Practices and Social Mechanisms for Building Resilience***, ed. F Berkes, C Folke, 390-413. Cambridge, MA: Cambridge Univ. Press
- Agrawal A. 1994. Rules, rule making, and rule breaking: Examining the fit between rule systems and resource use. In ***Rules, Games, and Common-Pool Resources***, ed. E Ostrom, R Gardner, JM Walker, 267-82. Ann Arbor: Univ. of Michigan Press
- Agrawal A, Yadama GN. 1997. How do local institutions mediate market and population pressures on resources? Forest ***panchayats*** in Kumaon, India. ***Development and Change*** 28(3):435-65
- Alcorn JB, Toledo V. 1998. Resilient resource management in Mexico's forest ecosystems: The contribution of property rights. In ***Linking Social and Ecological Systems. Management Practices and Social Mechanisms for Building Resilience***, ed. F Berkes, C Folke, 216-49. Cambridge, MA: Cambridge Univ. Press
- Anderson L G. 1986. ***The Economics of Fisheries Management***. Rev. ed. Baltimore, MD: Johns Hopkins Univ. Press
- Anderson L G. 1992. Consideration of the potential use of individual transferable quotas in U.S. fisheries. ***The National ITQ Study Report*** 1:1-71
- Anderson PW, Arrow KJ, Pines D, eds. 1988. ***The Economy as an Evolving Complex System***. Redwood City, CA: Addison-Wesley
- Arnold JEM. 1998. ***Managing Forests as Common Property***. Rome, Italy: Food & Agriculture Organization of the United Nations, FAO Forestry Paper no. 136
- Arnold JEM, Campbell, JG. 1986. Collective management of hill forests in Nepal: The community Forestry development project. In ***Proceedings of the Conference on Common Property Resource Management***, National Research Council, 425-54. Washington, DC: National Academy Press
- Arnold JEM, Stewart WC. 1991. ***Common Property Resource Management in India***. Oxford: Oxford Forestry Institute, Tropical Forestry Papers no. 24
- Ascher W. 1995. ***Communities and Sustainable Forestry in Developing Countries***. San Francisco, CA: ICS Press

- Baland J-M, Platteau J-P. 1996. *Halting Degradation of Natural Resources: Is There a Role for Rural Communities?* Oxford: Clarendon Press
- Bendor JB. 1985. *Parallel Systems. Redundancy in Government.* Berkeley: Univ. of California Press
- Bendor JB. 1987. In good times and bad: Reciprocity in an uncertain world. *American Journal of Political Science* 31(3): 531-58
- Bendor JB, Mookherjee D. 1990. Norms, third-party sanctions, and cooperation. *Journal of Law, Economics, and Organization* 6:33-63
- Benjamin P, Lam WF, Ostrom E, Shivakoti G. 1994. *Institutions, Incentives, and Irrigation in Nepal.* Decentralization: Finance & Management Project Report. Burlington, VT: Associates in Rural Development
- Berkes F. 1986. Local-level management and the commons problem: A comparative study of Turkish coastal fisheries. *Marine Policy* 10:215-29
- Berkes F, ed. 1989. *Common Property Resources. Ecology and Community-Based Sustainable Development.* London: Belhaven Press
- Berkes F, Feeny D, McCay BJ, Acheson JM. 1989. The benefits of the commons. *Nature* 340(6229): 91-93
- Blomquist W. 1992. *Dividing the Waters: Governing Groundwater in Southern California.* San Francisco, CA: ICS Press
- Boyd R, Richerson PJ. 1985. *Culture and the Evolutionary Process.* Chicago: Univ. of Chicago Press
- Bromley DW. 1982. *Improving Irrigated Agriculture: Institutional Reform and the Small Farmer.* Washington, DC: World Bank Staff Working Paper no. 531
- Bromley DW, Feeny D, McKean MA, Peters P, Gilles J, et al, eds. 1992. *Making the Commons Work: Theory, Practice, and Policy.* San Francisco, CA: ICS Press
- Campbell DT. 1969. Reforms as experiments. *American Psychologist* 24(4): 409-29
- Campbell DT. 1975. On the conflicts between biological and social evolution and between psychology and moral tradition. *American Psychologist* 30(11): 1103-26
- Copes P. 1986. A critical review of the individual quota as a device in fisheries management. *Land Economics* 62(3):278-91
- Cordell JC, McKean, MA. 1992. Sea tenure in Bahia, Brazil. In *Making the Commons Work: Theory, Practice, and Policy*, ed. DW Bromley et al, 183-205. San Francisco, CA: ICS Press
- Coward EW, Jr. 1979. Principles of social organization in an indigenous irrigation system. *Human Organization* 38:28-26

- Coward EW, Jr. 1985. Technical and social change in currently irrigated regions: Rules, roles, and rehabilitation. In ***Putting People First: Sociological Variables in Rural Development***, ed. MM Cemea, 27-51. New York: Oxford Univ. Press
- Crawford SES, Ostrom E. 1995. A grammar of institutions. ***American Political Science Review*** 89(3):582-600
- Cruz WD. 1986. Overfishing and conflict in a traditional fishery: San Miguel Bay, Philippines. In ***Proceedings of the Conference on Common Property Resource Management***, National Research Council, 115-35. Washington, DC: National Academy Press
- Curtis D. 1991. ***Beyond Government: Organisations for Common Benefit***. London: Macmillan
- Dasgupta P. 1982. ***The Control of Resources***. Cambridge, MA: Harvard Univ. Press
- Deadman P. 1997. ***Modeling individual behavior in common pool resource management experiments with autonomous agents***. PhD thesis. Univ. of Arizona, Tucson
- de los Reyes RP. 1980. ***Managing Communal Gravity Systems: Farmers' Approaches and Implications for Program Planning***. Quezon City, Philippines: Ateneo de Manila University, Institute of Philippine Culture
- Elster J. 1989. ***The Cement of Society. A Study of Social Order***. Cambridge: Cambridge Univ. Press
- Feeny DH. 1988. Agricultural expansion and forest depletion in Thailand, 1900-1975. In ***World Deforestation in the Twentieth Century***, ed. JF Richards, RP Tucker, 112-43. Durham, NC: Duke Univ. Press
- Fortmann L, Bruce JW. 1988. ***Whose Trees? Proprietary Dimensions of Forestry***. Boulder, CO: Westview Press
- Frohlich N, Oppenheimer JA, Eavey CL. 1987. Choices of principles of distributive justice in experimental groups. ***American Journal of Political Science*** 31(3):606-36
- Gadgil M, Iyer, P. 1989. On the diversification of common-property resource use by Indian society. In ***Common Property Resources: Ecology and Community-Based Sustainable Development***, ed. F Berkes, 240-72. London: Belhaven Press
- Gardner R, Ostrom E. 1991. Rules and games. ***Public Choice*** 70(2):121-49
- Gibson C, McKean MA, Ostrom E. 1998. ***Forest Resources and Institutions***. Forests, Trees and People Programme, Working Paper no. 3. Rome, Italy: Food and Agriculture Organization of the United Nations
- Gordon HS. 1954. The economic theory of a common property resource: The fishery. ***Journal of Political Economy*** 62:124-42
- Hardin G. 1968. The tragedy of the commons. ***Science*** 162:1243-48

- Hess C. 1996. *Common-Pool Resources and Collective Action: A Bibliography*, vol. 3. Bloomington: Indiana Univ., Workshop in Political Theory and Policy Analysis
- Higgs R. 1996. Legally induced technical regress in the Washington salmon fishery. In *Empirical Studies in Institutional Change*, ed. LJ Alston, T Eggertsson, DC North, 247-79. New York: Cambridge Univ. Press
- Hilton R. 1992. Institutional incentives for resource mobilization: An analysis of irrigation schemes in Nepal. *Journal of Theoretical Politics* 4(3):283-308
- Holland JH. 1995. *Hidden Order. How Adaptation Builds Complexity*. Reading, MA : Addison-Wesley
- Jacob F. 1977. Evolution and tinkering. *Science* 196(4295) (June 10): 1161-66
- Jodha NS. 1990. Depletion of common property resources in India: Micro-level evidence. In *Rural Development and Population: Institutions and Policy*, ed. G McNicoll, M Cain, 261-83. Oxford: Oxford Univ. Press
- Jodha NS. 1996. Property rights and development. In *Rights to Nature*, ed. SS Hanna, C Folke, K-G Maler, 205-22. Washington, DC: Island Press
- Lam WF. 1998. *Governing Irrigation Systems in Nepal: Institutions, Infrastructure, and Collective Action*. Oakland, CA: ICS Press
- Landau M. 1969. Redundancy, rationality, and the problem of duplication and overlap. *Public Administration Review* 29(4):346-58
- Landau M. 1973. Federalism, redundancy, and system reliability. *Publius* 3(2): 173-96
- Lansing JS. 1991. *Priests and Programmers. Technologies of Power in the Engineered Landscape of Bali*. Princeton, NJ: Princeton Univ. Press
- Lansing JS, Kremer JN. 1994. Emergent properties of Balinese water temple networks: Co-adaption on a rugged fitness landscape. In *Artificial Life III. Studies in the Sciences of Complexity*, Vol. XVII, ed. CG Langton, 201-23. Reading, MA: Addison-Wesley
- Levi M. 1988. *Of Rule and Revenue*. Berkeley: Univ. of California Press
- Levine G. 1980. The relationship of design, operation, and management. In *Irrigation and Agricultural Development in Asia*, ed. EW Coward, 51-64. Ithaca, NY: Cornell Univ. Press
- Maass A, Anderson RL. 1986. . . . *and the Desert Shall Rejoice: Conflict, Growth, and Justice in Arid Environments*. Malabar, FL: RE Krieger
- Martin F. 1989/1992. *Common-Pool Resources and Collective Action: A Bibliography*, vols. 1 & 2. Bloomington: Indiana Univ., Workshop in Political Theory and Policy Analysis
- McCay BJ, Acheson JM. 1987. *The Question of the Commons: The Culture and Ecology of Communal Resources*. Tucson: Univ. of Arizona Press

- Mehra S. 1981. *Instability in Indian Agriculture in the Context of the New Technology*. Washington, DC: International Food Policy Research Institution, Research Report no. 25
- Morrow CE, Hull RW. 1996. Donor-initiated common-pool resource institutions: The case of the Yanasha forestry cooperative. *World Development* 24(10): 1641-57
- Nelson RR, Winter SG. 1982. *An Evolutionary Theory of Economic Change*. Cambridge, MA: Harvard Univ. Press
- Netting RMcC. 1974. The system nobody knows: Village irrigation in the Swiss Alps. In *Irrigation's Impact on Society*, ed. TE Downing, M Gibson, 67-75. Tucson: Univ. of Arizona Press
- Netting RMcC. 1993. *Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture*. Stanford, CA: Stanford Univ. Press
- Ostrom E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. New York: Cambridge Univ. Press
- Ostrom E. 1992. *Crafting Institutions for Self-Governing Irrigation Systems*. San Francisco, CA: ICS Press
- Ostrom E. 1996. Incentives, rules of the game, and development. In *Proceedings of the Annual World Bank Conference on Development Economics 1995*, 207-34. Washington, DC: The World Bank
- Ostrom E. 1998a. A behavioral approach to the rational choice theory of collective action. *American Political Science Review* 92(1): 1-22
- Ostrom E. 1998b. Self-governance of common-pool resources. In *The New Palgrave Dictionary of Economics and the Law*, ed. P Newman, forthcoming. London: Macmillan Press
- Ostrom E, Agrawal A, Blomquist W, Schlager E, Tang SY, et al. 1989. *CPR Coding Manual*. Bloomington: Indiana Univ., Workshop in Political Theory and Policy Analysis
- Ostrom E, Gardner R, Walker JM. 1994. *Rules, Games, and Common-Pool Resources*. Ann Arbor: Univ. of Michigan Press
- Ostrom E, Walker JM. 1997. Neither markets nor states: Linking transformation processes in collective action arenas. In *Perspectives on Public Choice: A Handbook*, ed. DC Mueller, 35-72. Cambridge: Cambridge Univ. Press
- Ostrom E, Walker JM, Gardner R. 1992. Covenants with and without a sword: Self-governance is possible. *American Political Science Review* 86(2):404-17
- Ostrom V. 1987. *The Political Theory of a Compound Republic: Designing the American Experiment*. 2d rev. ed. San Francisco, CA: ICS Press
- Ostrom V. 1991. *The Meaning of American Federalism: Constituting a Self-Governing Society*. San Francisco, CA: ICS Press

- Ostrom V. 1997. *The Meaning of Democracy and the Vulnerability of Democracies: A Response to Tocqueville's Challenge*. Ann Arbor: Univ. of Michigan Press
- Ostrom V, Feeny D, Picht H, eds. 1993. *Rethinking Institutional Analysis and Development: Issues, Alternatives, and Choices*. 2d ed. San Francisco, CA: ICS Press
- Ostrom V, Tiebout C M, Warren R. 1961. The organization of government in metropolitan areas: A theoretical inquiry. *American Political Science Review* 55:831-42
- Palanisami K. 1982. *Managing tank irrigation systems: Basic issues and implications for improvement*. Presented at workshop on Tank Irrigation: Problems and Prospects
- Panayotou T, Ashton, PS. 1992. *Not by Timber Alone: Economics and Ecology for Sustaining Tropical Forests*. Washington, DC: Island Press
- Pinkerton E, ed. 1989. *Co-operative Management of Local Fisheries: New Directions for Improved Management and Community Development*. Vancouver: Univ. of British Columbia Press
- Poffenberger M, McGean B. 1996. *Village Voices, Forest Choices: Joint Forest Management in India*. New Delhi: Oxford Univ. Press
- Repetto R. 1986. *Skimming the water: Rent-seeking and the performance of public irrigation systems*. Research report no. 4. Washington, DC: World Resources Institute
- Rocco E, Warglein M. 1995. Computer mediated communication and the emergence of 'electronic opportunism'. Working paper RCC#13659. Universita degli Studi di Venezia
- Schlager E. 1990. *Model specification and policy analysis: The governance of coastal fisheries*. PhD thesis. Indiana Univ., Bloomington
- Schlager E. 1994. Fishers' institutional responses to common-pool resource dilemmas. In *Rules, Games, and Common-Pool Resources*, ed. E Ostrom, R Gardner, JM Walker, 247-65. Ann Arbor: Univ. of Michigan Press
- Schlager E, Blomquist W, Tang SY. 1994. Mobile flows, storage, and self-organized institutions for governing common-pool resources. *Land Economics* 70(3):294-317
- Scott AD. 1955. The fishery: The objectives of sole ownership. *Journal of Political Economy* 63:116-24
- Sengupta N. 1991. *Managing Common Property: Irrigation in India and the Philippines*. New Delhi: Sage
- Shepherd G. 1992. *Managing Africa's Tropical Dry Forests: A Review of Indigenous Methods*. London: Overseas Development Institute
- Sherman K, Laughlin T, eds. 1992. *NOAA Technical Memorandum NMFS-f/NEC 91. The Large Marine Ecosystem (LME) Concept and Its Application to Regional Marine Resource Management*. Woods Hole: Northeast Fisheries Science Center

- Singleton S. 1998. *Constructing Cooperation. The Evolution of Institutions of Co-management in Pacific Northwest Salmon Fisheries*. Ann Arbor: Univ. of Michigan Press
- Singleton S, Taylor M. 1992. Common property economics: A general theory and land use applications. *Journal of Theoretical Politics* 4:309-24
- Spooner B. 1974. Irrigation and society: The Iranian plateau. *In Irrigation's Impact on Society*, ed. TE Downing, M Gibson, 43-57. Tucson: Univ. of Arizona Press
- Tang SY. 1992. *Institutions and Collective Action: Self-Governance in Irrigation*. San Francisco, CA: ICS Press
- Tang SY. 1994. Institutions and performance in irrigation systems. In *Rules, Games, and Common-Pool Resources*, ed. E Ostrom, R Gardner, JM Walker, 225-45. Ann Arbor: Univ. of Michigan Press
- Taylor M. 1982. *Community, Anarchy, and Liberty*. New York: Cambridge Univ. Press
- Thomson JT. 1977. Ecological deterioration: Local-level rule making and enforcement problems in Niger. In *Desertification: Environmental Degradation in and around Arid Lands*, ed. MH Glantz, 57-79. Boulder, CO: Westview Press
- Thomson JT, Feeny D, Oakerson, RJ. 1992. Institutional dynamics: The evolution and dissolution of common-property resource management, *la. Making the Commons Work: Theory, Practice, and Policy*, ed. DW Bromley et al, 129-60. San Francisco, CA: ICS Press
- Wade R. 1988. The management of irrigation systems: How to evoke trust and avoid prisoners' dilemmas. *World Development* 26(4):489-500
- Wade R. 1994. *Village Republics: Economic Conditions for Collective Action in South India*. San Francisco, CA: ICS Press
- Weissing FJ, Ostrom E. 1991a. Crime and punishment: Further reflections on the counterintuitive results of mixed equilibria games. *Journal of Theoretical Politics* 3(3):343-50
- Weissing FJ, Ostrom E. 1991b. Irrigation institutions and the games irrigators play: Rule enforcement without guards. In *Game Equilibrium Models II: Methods, Morals, and Markets*, ed. R Selten, 188-262. Berlin: Springer-Verlag
- Weissing FJ, Ostrom E. 1993. Irrigation institutions and the games irrigators play: Rule enforcement on government- and farmer-managed systems. In *Games in Hierarchies and Networks: Analytical and Empirical Approaches to the Study of Governance Institutions*, ed. FW Scharpf, 387-428. Frankfurt am Main: Campus Verlag; Boulder, CO: Westview Press
- Wilson JA. 1997. Maine fisheries management initiative. In *The Social Impacts of Individual Transferable Quotas*, ed. G Palsson, 335-53. Copenhagen: TemaNord.
- Wilson JA, Acheson JM, Kleban M, Metcalfe M. 1994. Chaos, complexity, and community management of fisheries. *Marine Policy* 18:291-305

- Wilson JA, French J, Kleban P, McKay SR, Townsend, R. 1991. Chaotic dynamics in a multiple species fishery: A model of community predation. *Ecological Modelling* 58:303-22
- Wilson JA, Low B, Costanza R, Ostrom E. Forthcoming. Scale misperceptions and the spatial dynamics of a social-ecological system. *Ecological Economics*
- Yoder RD. 1991. Peer training as a way to motivate institutional change in farmer-managed irrigation systems. In *Proceedings of the Workshop on Democracy and Governance*, Decentralization: Finance & Management Project Report, 53-67. Burlington, VT: Associates in Rural Development
- Yoder RD. 1994. *Locally Managed Irrigation Systems*. Colombo, Sri Lanka: International Irrigation Management Institute



**Table 1** Variables used in boundary rules to define who is authorized to appropriate from a resource

Residency or membership	Personal characteristics	Relationship with resource
National	Ascribed	Continued use of resource
Regional	Age	
Local community	Caste	Long-term rights based on:
Organization (e.g. co-op)	Clan	Ownership of a proportion of annual flow of resource units
	Class	Ownership of land
	Ethnicity	Ownership of non-land asset (e.g. berth)
	Gender	Ownership of shares in a private organization
	Race	Ownership of a share of the resource system
	Acquired	
	Education level	Temporary use-rights acquired through:
	Skill test	Auction
		Per-use fee
		Licenses
		Lottery
		Registration
		Seasonal fees
		Use of specified technology

**Table 2** Types of authority rules

Allocation formula for appropriation rights	Basis for allocation formula
Percentage of total available units per period	Amount of land held
Quantity of resource units per period	Amount of historical use
Location	Location of appropriator
Time slot	Quantity of shares of resource owned
Rotational order	Proportion of resource flow owned
Appropriate only during open seasons	Purchase of periodic rights at auction
Appropriate only resource units meeting criteria	Rights acquired through periodic lottery
Appropriate whenever and wherever	Technology used
	License issued by a governmental authority
	Equal division to all appropriators
	Needs of appropriators (e.g. type of crop)
	Ascribed characteristic of appropriator
	Membership in organization
	Assessment of resource condition

**Table 3** Rule configurations and appropriation situations

Rule configurations	Appropriation situations							
	A	B	C	D	E	F	G	H
<b>Boundary rules</b>								
Local residency	1	1	1	1	0	0	0	0
Member of local co-op	0	1	0	1	1	1	1	1
<b>Authority rules</b>								
Appropriate in location	1	0	0	0	1	0	1	0
Rotate in time	1	1	0	0	1	1	0	1
<b>Payoff rules</b>								
Fines	0	0	1	1	0	0	1	1
Loss of rights	0	0	0	0	0	0	1	1
<b>Position rules</b>								
All symmetric	1	1	1	1	0	0	0	0
Guard created	0	0	0	0	1	1	1	1
<b>Information rules</b>								
Infractions are recorded	0	0	0	1	1	0	0	1
Appropriation is recorded	0	0	0	0	0	0	0	1
<b>Scope rules</b>								
Forbidden access to refugia	0	0	1	0	1	0	1	1
<b>Aggregation rules</b>								
Must appropriate in teams	0	0	0	0	0	0	0	1