Order out of Chaos: The Case for Parametric Fisheries Management

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Order out of Chaos

The Case for Parametric Fisheries Management

> Twentieth century science will be remembered for just three things: relativity, quantum mechanics and chaos.
>
> —James Gleick, *Chaos: Making a New Science*

THE PAST THREE DECADES have seen the decline of some of the world's most important fisheries. In the United States, every major fishery in the Atlantic, Pacific, and Gulf of Mexico has witnessed stock depletion and reduced catches.[1] The fact that these stocks have been under management for decades means that we are witnessing a failure not only of stocks but of policy as well.

While there is general agreement that current management practices are not working well, there is no agreement about the cause of the problem. Most administrators and scientists employed in fisheries management agencies tend to believe that the science is sound and that the problems are political in nature. That is, they believe the management plans are well conceived but are not implemented due to the self-serving activities of the fishing industry (Sullivan 1987:2). Others are not so sanguine. There is a growing conviction, which we share, that the science itself is seriously flawed and is leading to ineffective policies.

In this essay, we bring together the ethnography of many fishing societies around the world and the theory of chaos to propose another way to manage fisheries. Essentially we argue that fisheries management in the industrial West would be well advised to emulate management practices of a large number of peasant and tribal societies, which are more consistent with fisheries biology and the chaotic nature of marine resources.

Since its inception in the 1960s, the theory of chaos has progressed from a preoccupation of a small group of physical scientists and mathematicians to a flourishing academic enterprise involving literally thousands of people in mathematics, the sciences, and increasingly in the social sciences. While most anthropologists are vaguely familiar with the ideas of chaos and complexity, these notions have not been used extensively in anthropology. There are some notable exceptions including Paul Friedrich's (1988:435–444) review of James Gleick's 1987 book, Thomas Park's (1992) use of chaos theory to analyze floods and the development of stratification in early civilization, and P. Philippe's (1993) application of chaos to epidemiology. More to the point, a number of articles appeared in *Maritime Anthropological Studies* linking chaos and complexity with changes in fish stocks, the behavior of fishers, and the nature of maritime communities.[2]

Among maritime anthropologists it is axiomatic that fisheries scientists and those who use those resources hold different views about the way oceans work and thus have different ideas about how to manage them. Estellie Smith cogently phrases these different perceptions by saying that population dynamicists tend to see the factors controlling the size of fish stocks as "ordered, balanced and in dynamic equilibrium" (Smith 1990:5). People in the fishing industry, she says, see them as far more "unpredictable" and even "chaotic." These observations are mirrored by Palsson (1994:918–921), who points out that folk knowledge of fishermen assumes the oceans are "complex" and in "flux."

Between 1989 and 1991, those involved in the University of Maine Chaos Project developed a model of fish stocks in the Gulf of Maine. This model strongly buttresses the idea that the size of fish stocks changes chaotically (Wilson et al. 1991a, 1991b). Managing such systems, we argue, calls for a different approach—influencing the ecological variables and fishing practices that are parameters in our model. We call this the parametric approach.[3]

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In this essay, we first review the scientific underpinning of the approach to management advocated by most fisheries biologists, which we call the numerical approach. Then we describe the ways in which societies in third-world countries manage their fisheries. We next discuss aspects of the theory of chaos and argue that the kinds of regulatory practices needed to manage chaotically fluctuating fish stocks are exactly those seen in the fishing communities in third-world countries. Finally, we assess the effectiveness of parametric management using observations of anthropologists who have studied local-level or folk management systems and data from the Maine lobster industry.

Numerical Management of Fisheries

Stock-Recruitment Models

The basis of "scientific" management efforts is stock-recruitment models, which are essentially concerned with population sizes of fish stocks. Such models are based on the presupposition that marine ecological systems tend toward equilibrium. That is, it is assumed that there is a normal population size for any species or set of stocks in marine ecosystems (Holling 1994). If a consistent level of fishing effort is put on a fish stock, there will be a tendency toward a predictable population size.[4]

The central idea of such models is that the long-term abundance or sustainability of a species is strongly linked to the amount of exploitative effort on that stock. The relationship between stock size and fishing effort can be described mathematically. The theory assumes that when stocks are low due to overfishing, the larger the parent stock, the larger the number of future additions to the population (recruitment). These models lead unerringly to policies designed to regulate the quantity of fish that can be taken.[5]

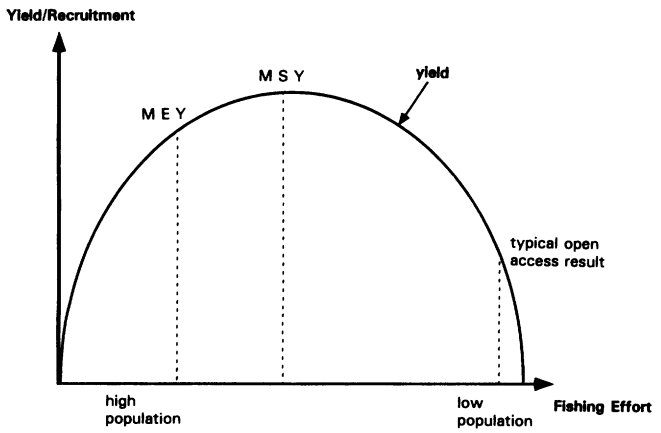

Figure 1
Relationship between fishing effort, fish population, and recruitment.

In the past several decades a good deal of work has been done to refine this model. The essential idea can be explained in terms of one simple graph, which is a modification of the famous Schaeffer curve for fisheries.

At low levels, effort tends to reduce population size only slightly. Increasing amounts progressively reduce the population. At high levels of effort, which typically occur in open access fisheries, populations will be low, and the reproductive ability of the stock will be low as well. If fishing mortality exceeds this stock's reproductive ability, populations will fall further. The objective of management then is to limit effort to the point where maximum economic yield (MEY) occurs or where maximum sustainable yield (MSY) results (Wieland 1992). (See Figure 1.) In either case, effort can be limited by rules designed to lower mortality on fish, or directly by a quota (Cushing 1988:276). At present, administrators, economists, and scientists are much taken with the idea of ITQs, individual transferable quotas, which promise not only to control the amount of fishing but also to achieve economic efficiency (Anderson 1992). It is critical to note that the objective of numerical management is to control the tonnage of fish caught. There is no concern for the effects of fishing on the broader environment and indirectly on the sustainability of the fish populations.

Empirical research has been unable to demonstrate that these stock-recruitment relationships exist in most cases.[6] There have been cases where large year-classes of fish came out of small parent stocks. In other cases, increases in effort have apparently had little effect on recruitment, such as in the Maine lobster fishery. As the biologist Nils Daan states, "The recruitment problem has not been solved" (1990:382).

Despite the ambiguity of the evidence mentioned above, fisheries managers have steadfastly maintained their faith in stock-recruitment models and have based their management efforts on this body of theory. A recent article in *Science* quotes one fisheries biologist as saying, "Fish stocks collapse because of plain simple overfishing" (Barinaga 1995:1043). He speaks for the majority of those in the profession.

Top-Down Management

In virtually all modern industrialized countries, controls on fishing effort are managed by centralized governments in very large units or even the entire range of the species. Reliance on top-down management techniques stems in part from the assumption that those using natural resources are strongly motivated to overexploit them and cannot generate institutions to man-

age them effectively. Management must be in the hands of government.[7] These assumptions are part of the theory of "common property" resources, which is perhaps the most influential body of theory guiding efforts to manage resources in modern Western countries.[8]

For those trained in scientific management, it is anathema to manage a species over only part of its range. It makes no sense, from a scientist's point of view, 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 must be large (Sherman and Laughlin 1992).

Scientific Management: Case Studies

Although there are common threads running through attempts to manage marine fisheries in modern industrial countries, actual regulations vary considerably from fishery to fishery. They have met with varying degrees of success. Between 1977 and 1980, the groundfish of the Gulf of Maine were managed by the federal government of the United States working through the New England Regional Fisheries Management Council. A mesh size regulation was established, but the primary management tools were trip quotas and three-month quotas. That is, a quota was established for three size-classes of vessels and a total quota on each of the managed species was established for each three-month period. When the total allowable catch (TAC) was reached, fishing was banned for the remainder of the three-month period (Acheson 1984:321; Dewar 1983:176–177). This effort failed due to massive political agitation and the fact that the self-reporting system led to widespread cheating and misreporting of catches (see Figure 2, Case 1).[9]

In New Zealand fisheries (see Figure 2, Case 2) reliance is placed on individual transferable quotas. A total allowable catch is set for each species to be managed. Then rights to fish for a portion of the catch are allocated to firms established in the fishery. These ITQs can be sold to other firms, a design that should ensure that ownership will "eventually rest with the most efficient harvesters" (Sissenwine and Mace 1991:149). In addition, licenses are limited, and a vessel buy-back program has been established to reduce the number of boats in many fisheries. Although the program is so new that it cannot be adequately assessed, Michael Sissenwine and Pamela Mace conclude it has led to no improvement in the fishery, from a biological or an economic standpoint (1991:152–153).

Not all efforts to manage fisheries using "scientific methods" have ended in failure. One such fishery is the salmon fishery of Alaska (Figure 2, Case 3). In the early decades of the century, salmon fishing was uncontrolled, and such a high percentage of the fish were taken that low catches were experienced in the 1940s to 1960s. In an effort to improve catches, the number of salmon traps was reduced substantially, and in the 1970s a limited entry program was enacted, placing strict controls on the number of people and vessels allowed in the fishery (Royce 1989:8–12). Although there was considerable opposition from those excluded from the fishery, Alaskan salmon catches have improved, and the management plan remains in effect.

Fisheries Management Techniques in Folk Societies

Management of marine fisheries is found throughout the world in a large number of industrial and more traditional societies (Acheson 1981; Berkes 1989). However, there can be little question that the management practices in modern Western societies where scientific management is the rule are different from those used in peasant and tribal societies. Those differences can be clearly seen by comparing the data on the combinations of techniques used in societies summarized in Figures 2 and 3.[10]

Figure 2 contains information on seven societies in which fisheries management regulations are strongly or completely influenced by the scientific establishment, and management is in the hands of a central government. Most of these are modern industrial countries. Figure 3 contains information on the fishery regulations used in 29 societies (Cases 8 to 36) where traditional or folk management techniques are employed and scientists have had little if any influence.[11] Most of these systems of rules have been developed on the local level, usually by the users of the resources themselves. In such societies rules are enforced by informal community pressure or religious sanctions rather than by officials of a formally constituted government.

For our purposes there are two important insights offered by the data in Figures 2 and 3. First, in virtually all of the societies studied, resources are managed by political entities that have riparian rights over coastal areas. We believe that some kind of riparian control over territoriality is a necessary precondition for any other kind of resource management regulation.[12] A rule or regulation cannot apply generally. It can apply only within the territory of a group willing and able to enforce the rule.

The size of the units to be managed varies considerably. The management areas employed by the societies in Figure 2 are generally much larger than those in Figure 3. The large size of the units to be managed generally reflects the penchant of governments and

scientists to manage large areas or even the entire range of a species using top-down management techniques. The small size of the management units of the societies in Figure 3 is consistent with the fact that most are tribal groups or peasant societies, which typically have control over relatively small areas people know intimately (Johannes 1981:11–84; Murton 1980:75; Klee 1980:255 ff.). The fisheries management rules are consistent with the local culture and social structure.

Second, all of the rules and practices used in the 29 tribal and peasant societies in Figure 3 regulate "how" fishing is done. That is, they limit location, time, stage of life of the target species, or technology. None limit the amount of various species that can be caught. Use of quotas—the single most important concept and tool of scientific management—is conspicuous by its absence.[13] In the tribal societies on which we have data, there is only one instance where a quota is mentioned at all, and this was imposed by the Hudson's Bay Company in an attempt to regulate Cree exploitation of beaver after 1820 (Brightman 1987:122–123).

As is indicated by Figure 3, the rules and techniques used to manage fisheries in third-world societies (Cases 8 to 36) can be described in the same terms as those used in modern industrialized societies. However, these management techniques are the product of different cultures, and they are employed in a variety of combinations. This gives these management regimes a flavor not seen in traditional texts on fisheries management. A few examples will suffice to illustrate this point.

In Tokugawa Japan (Case 9), both land and sea were part of the fiefs of feudal lords. The people of fishing villages were allowed to fish in coastal waters only if they paid the lord. After a time village fishing territories evolved, but ownership still resided with the lord (Kalland 1984:11–12). Permission to use fish did not give unlimited rights of exploitation. Fishing was often restricted to certain seasons. Licenses needed to be obtained from the feudal authorities to take abalone and whales and to use large nets (Kalland 1984:22–24). Fisheries sanctuaries were also recognized and protected. However, no effort was made to limit the number of boats or the number of people involved in the fishery (Kalland 1984:23). Many of the latter techniques are in use in Japan today.

In Oceania, conservation efforts were rooted in the reef and lagoon tenure system. Inshore fishing grounds were considered the property of local villages, and access to them was allocated by the local village chief. Individuals from other communities were generally allowed to fish in these waters for a fee. In addition, there were rules that protected certain species. On one island in the Palau group (Case 10), fishers were prohibited from catching one predator fish that drives other species onto the shore, so that it could continue its good work in the service of humans. R. E. Johannes (1981:64–67) also reports that turtles were thought to be owned by God, and neither the adult turtles nor turtle eggs could be taken. Throughout Oceania, fish considered an emergency food supply could not be caught in good weather when other species were available. There was also a strong conservation ethic on these islands. People were expected not to take more fish than they could consume. Ideally one had enough skill to be able to find fish whenever the need arose.

In India another combination of practices and norms was used to manage the fishery and other natural resources (Case 29). There was a system of caste fishing territories, which lasted until recent times (Gadgil 1985:139). In addition, the Hindu month of Sravana

CASE #	SOCIETY	REFERENCE	RESOURCE	AREAS	LIMITED ACCESS	SEASONAL LIMITS	TECHNOLOGY	PROTECT BREEDING STOCK	PROTECT YOUNG	SIZE LIMITS	CONSERVATION ETHIC	PROTECT OVERCROWDING	OTHER	QUOTA
1	NEW ENGLAND	ACHESON 1984/DEWAR 1983	GROUND FISH		X		X							X
2	NEW ZEALAND	SISSENWINE AND MACE 1991	FIN FISH	X										X
3	ALASKA	ROYCE 1989	SALMON	X	X		X							
4	MEXICO	MCGOODWIN 1987	SHRIMP	X	X	X			X					X
5	MAINE	ACHESON 1988	LOBSTER	X	X		X	X	X	X				
6	LOFOTEN ISLANDS	JENTOFT AND KRISTOFERSEN 1989	COD	X			X						X	
7	ICELAND	DURRENBERGER AND PALSSON 1995	FISH	X	X	X	X		X	X				X

Figure 2
Management techniques used in societies under scientific management.

CASE #	SOCIETY	REFERENCE	RESOURCE	AREAS	LIMITED ACCESS	SEASONAL LIMITS	TECHNOLOGY	PROTECT BREEDING STOCK	PROTECT YOUNG	SIZE LIMITS	CONSERVATION ETHIC	PROTECT OVERCROWDING	OTHER	QUOTA
8	CAYE CALKER, BELIZE	SUTHERLAND 1986	SPINY LOBSTER	X	X	X		X						
9	JAPAN (TOKUGAWA PERIOD)	KALLAND 1984	FISH	X		X	X							
10	PALAU	JOHANNES 1981	FISH	X				X	X		X			
11	SRI LANKA	ALEXANDER 1980	FIN FISH	X	X							X		
12	OKINAWA	AKIMICHI AND RUDDLE 1984	FISH	X	X	X	X			X				
13	CREE	BERKES 1987	FISH	X			X		X		X			
14	OCEANIA	BAINES 1989/JOHANNES 1978	FISH	X	X	X		X	X	X	X			
15	NEWFOUNDLAND	MARTIN 1979	FIN FISH	X			X					X		
16	COASTAL JAPAN	RUDDLE 1989	FIN FISH	X	X		X							
17	EQUADOR	SOUTHON 1989	FISH									X		
18	KOYUKON	NELSON 1982	FISH					X			X			
19	OJIBWA	BISHOP 1970	GAME AND FISH	X							X			
20	TITICACA	LEVEIL AND ORLOVE 1990	GAME AND TOTORA	X	X									
21	YOLUNGU (AUST.)	WILLIAMS 1982	FISH, TURTLES, SHELLFISH, EMU	X	X									
22	POHNPEI	FOSTER AND POGGIE 1993	FISH	X	X	X	X						X	
23	KIRIBAH-TUVALU	ZANN 1985	FISH	X	X	X	X				X		X	
24	ROCKCREE	BRIGHTMAN 1987	FISH AND BEAVERS	X			X	X	X				X	
25	PONAM, NEW GUINEA	CARRIER 1987	FISH	X	X									
26	BORNEO	VONDAL 1987	FISH, DUCKS, SNAILS	X			X							
27	BRAZIL	ROBBEN 1994a, 1994b	FIN FISH	X			X		X					
28	ZEELAND	VAN GINKEL 1989	OYSTERS	X	X									
29	INDIA	GADGIL 1985	FISH, ANIMALS, PLANTS	X		X		X					X	
30	MALAITA	AKIMICHI 1981	FISH	X	X	X							X	
31	TURKEY	BERKES 1986	FISH	X		X	X	X		X				
32	TORRES STRAIT	NIETSCHMANN 1985	FISH	X					X				X	
33	NILE DELTA	ROWNTREE et al. 1984	FISH	X		X		X					X	
34	KOREA	HAN 1972	MYOK	X	X									
35	MEXICO	MILLER 1989	LOBSTER	X	X									
36	HARAPA, PAKISTAN	BELCHER 1993	FISH				X						X	

Figure 3
Management techniques used in 29 folk societies.

(August) was a closed season when no fish or meat could be harvested, and the use of fish poisons was limited to a few days coinciding with a communal festival. There were prohibitions on fishing during mating season to protect the breeding stock. Sacred ponds were protected, providing a sanctuary (Gadgil 1985:143). All resources, including fish, were considered the property of the gods and not of the caste, and the gods' permission was needed before they could be harvested. Madhav Gadgil (1985:135) argues that these practices maintained populations at sustainable levels.

Managing Chaotic Fisheries

Why have so many societies managed fisheries by essentially regulating how people fish? We argue that this type of management is congruent with the nature of fish populations, which is probably highly chaotic. In addition, this type of management involves moderate information and enforcement costs, resulting in the development of effective institutions. In stark contrast to what most fisheries biologists believe, we believe it is the only kind of management regime that is likely to be effective in the long run, a principle that people in non-Western societies have discovered.

Recent work by our research group strongly suggests that even simple communities of fish exhibit chaotic population patterns; the population level of individual species varies unpredictably within limits even though it is bounded within a range. These conclusions are the result of work with a simulation model reported in James A. Wilson et al. (1991a, 1991b), which approximates the conditions (spawning, growth, and mortality figures) seen in a typical groundfish population in temperate waters. The model has an age-structured community of five species with a large amount of niche

overlap. It is assumed that the size of the community as a whole is limited by food constraints that set an overall carrying capacity. Interactions among the five species are marked by what Sissenwine (1984, 1986) calls community predation—big fish eat little fish indiscriminately. This is the primary cause of the chaotic swings in population. In short, as the community approaches its carrying capacity, the scarcity of food results in more small fish being eaten by larger fish. D. H. Cushing (1977) has demonstrated that cannibalism produces swings in the population of a single species. Our model is a multiple-species version of the same phenomenon. The result is chaotic variation in stock sizes.

This model exhibits several characteristics that can be observed among marine systems. The total biomass of the community of fish is relatively stable, but the biomass of individual species can vary in unpredictable ways. In addition, there is compensation among species so that when the population of one declines, another increases to take its place. Last, in this model, as in observed fisheries, there is no relationship between the size of the spawning stock and recruitment.[14]

The model approximates the qualitative characteristics of fish and ocean ecosystems using parameters typical of ocean and fisheries systems. The output of our model mirrors the kind of unpredictable population changes observed in actual populations of fish over time. Others, such as Alan Hastings and Kevin Higgins (1994), also argue that marine systems are chaotic. However, there is certainly no consensus on this matter yet, and none will probably arise for a period of years.[15]

Under these conditions, the key question is, If fisheries are chaotic, how should they be managed? Answering this question necessitates some understanding of the nature of chaotic systems. Chaotic systems are not marked by a complete lack of order. Rather, physicists point out that chaotic systems are characterized by clear cause-and-effect relationships, but the complexity and nonlinearity of these relationships makes output of these systems highly unpredictable. These outcomes, however, take place within well-defined limits or ranges set by the parameters of the model. Usually in modeling—our efforts included—the parameters of the model are assumed constant. In models of biological systems, these parameters represent such things as spawning potential, growth rates, habitat, and migration. In the real world, these basic input factors (parameters) remain relatively stable over the course of time. Their stability is the reason that fish populations can be expected to vary within certain limits, even though population changes will remain unpredictable. This implies that if the parameters of the system remain relatively constant, the variation of fish populations will remain within normal or historic limits.

In addition, chaotic systems are extremely sensitive to "initial conditions" (Gleick 1987:22–23). This means that small changes in current circumstances can produce huge changes in the future state of a chaotic system. Where groundfish are concerned, a large amount of fishing on a concentration of spawning fish or a storm might result in a small year-class. On the other hand, a large amount of food, favorable water temperatures, or favorable currents near a spawning area might result in high recruitment several years hence.

Theoretically, one should be able to predict the effects of such initial conditions on fish populations, given the deterministic nature of chaotic systems. The number of relationships is so large and the feedback mechanisms in the system are so complicated, however, that a huge amount of accurate, fine-grained, continuously updated data would be necessary to make accurate prediction possible.[16] Given how sensitive such models are to initial conditions, small variations or inaccuracies in measurement would likely result in huge errors in prediction. Under these conditions, accurate prediction is a practical impossibility.

The difficulties of prediction are underscored by the fact that in the model used by the researchers in our group, all of the relationships, parameters, and initial conditions are known because they are defined by the programmer. Under these conditions, even a small change in the third or fourth decimal place of the initial variables will produce results that quickly diverge from predictions. In actual fisheries, we are fortunate to be able to assess stocks within 30 percent of their actual size; we can only guess at community predation interrelationships; and great variations exist in estimates of factors such as natural mortality.[17]

Even if fisheries are not chaotic, they are certainly complex, as Donald Ludwig et al. (1993) have pointed out. In either case, fisheries are unpredictable. The problem is how to manage without the ability to predict outcomes. Given our state of knowledge of interrelationships in fish communities and our real measurement capabilities, it is virtually impossible to predict the size of future stocks of fish. This means that in the real world, it is impossible to predict the outcomes, for example, of regulations to achieve maximum sustainable yield, or maximum economic yield, through measures such as a quota.

If stock-recruitment models cannot be used practically, what approach should be taken? Our modeling exercise gives a clue. The fact that the populations of fish vary within specifiable limits when the system parameters are undisturbed suggests that fisheries can be managed by maintaining those parameters. If this approach to management is taken, the goal of regulation would be to maintain critical life processes such as

spawning, to prohibit fishing during certain parts of the life cycle, and to maintain areas essential for the well-being of these species (such as breeding grounds, migration, and nursery areas). This can be accomplished by rules concerning fishing locations, fishing areas, and techniques. Of course, it is exactly this approach to management that is taken in so many tribal and peasant societies listed in Figure 3 (Cases 8 to 36). In these societies the emphasis is on maintaining the variables that affect fisheries systems—not the amount of fish taken. We call this approach parametric management. The goal of parametric managagement is not to attempt to control yields of fish but to maintain the system in a state where the normal range of variability is preserved (Wilson and Dickie 1995).

Enforcement Costs and the Creation of Institutions

Controlling how people fish minimizes information and enforcement costs, which makes it possible to generate effective conservation institutions. Numerical management, by way of contrast, tends to increase both kinds of costs, with detrimental effects on institutional development.

People in fishing communities in tribal and peasant areas develop and support rules affecting how fishing is done, because such rules are based on the knowledge they have about the resource and because they believe the rules are in their own best interests. Not only do they have an opportunity to learn about regular biological processes of target species, but it is essential that they obtain this information. If they are to succeed in fishing, they must know a great deal about the habits of various species, including feeding patterns, predation, life cycle, and places where fish will be over the seasonal round (including their migration routes, spawning areas, and nursery areas) (Johannes 1978, 1981:32–58). The fact that they exploit species only in small zones has facilitated their ability to learn about these species.

This knowledge is also an important ingredient in generating rules to conserve species. Those who exploit fish stocks for a number of years develop an excellent idea about what influences them. The conservation rules they develop are designed to maintain those biological processes they know or believe are essential for the well-being of the fish stocks on which their livelihood depends. They believe that rules designed to protect fish and animals at certain life-cycle stages are crucial, and they support them. The result is lower enforcement costs. Conversely, they are apt to be opposed to rules that are not based on biological reality and thus are judged to be ineffective. Johannes summarizes the situation nicely in writing about Oceania: "When fishermen do not understand the purposes of fishing regulations or perceive them as being imposed arbitrarily by outsiders they are not liable to look on them with favor or obey them voluntarily" (1981:198).

Moreover, rules influencing how people fish have another virtue: they lower enforcement cost by making policing relatively easy. It is easy to monitor whether people are fishing along a prohibited beach, or taking a forbidden species, or using illegal gear. It is entirely another matter to enforce a numerical rule, since this requires counting amounts of fish and keeping records of catches.

Many fisheries management regimes in the United States founder on exactly such shoals. Fishermen know that fisheries are chaotic, and policies that ignore this insight seem ineffective, unrealistic, and even foolish (Smith 1990:9). From the point of view of such people, obedience to rules based on stock-recruitment models imposes costs that will not result in future benefits. They are a poor investment.

The problems inherent in numerical management were underscored in the attempts to manage the groundfish stocks of the Gulf of Maine using trip quotas and three-month quotas (Case 1). The plan was monumentally unpopular, and the self-reporting system led to massive cheating. There were a good many arrests and a lot of political agitation (Acheson 1984). In 1980, this plan was put in abeyance and another substituted. In retrospect, it is apparent that the basic problem was that fishermen did not believe the rules would conserve the stocks. This led to cheating, which motivated still others to cheat in an effort to get their share of the fish. In the past, fishermen may have been suspicious of the figures on which science was based; now they knew such figures were completely fraudulent, since they were the source of them.

Vincent and Elinor Ostrom have done outstanding work analyzing the conditions under which institutions are generated to conserve resources. Elinor Ostrom points out that "where substantial temptation exists to engage in opportunistic behavior, no set of rules will be self enforcing" (1992:55). In the case of the New England groundfishery, the incentives made self-enforcement impossible, and the government did not have the resources to enforce the rules. As a result, large numbers of fishermen became "free riders," and the groundfish management plan, which constituted what Mancur Olsen would define as a public good, became impossible to maintain.[18] In this and many other cases, when fishermen do not believe a management plan will result in future benefits, the goals of individuals are not those of the society at large, enforcement costs grow, and management plans fail.[19]

How Well Does Parametric Management Conserve?

In the past decade, a number of maritime anthropologists have written on folk or local-level management. One of the themes running through this body of literature is that tragedies of the commons are not inevitable. People in local communities are capable of developing effective institutions to conserve resources and have done so in widespread parts of the world.[20] The effectiveness of these traditional folk management efforts stems from the fact that in tribal and peasant societies, conservation rules embody the principles of parametric management. They attempt to preserve basic biological processes rather than limit the amount of fish that can be taken. In addition, they are obeyed. In these societies, the rules promote the conservation of the resource in ways that reflect local norms, so that the goals of individuals and communities coincide. They are not imposed by a central government with little knowledge of the local area or personal stake in the outcome. Since there is an incentive to obey conservation rules, costs of enforcement are low, as are the incentives to be a free rider.

Despite the number of case studies and the strong assertions of a growing number of anthropologists, however, there is very little statistical data that local-level or folk management rules are effective in conserving the resource. The evidence is largely anecdotal. In some instances, authors have noted that resources have not crashed and have assumed that the sustained yields are due to folk management rules.[21] In other cases, historical changes are used as evidence. Johannes (1978, 1981:63–67) argues that the fisheries of Oceania declined dramatically after the traditional management system broke down under the pressures of Westernization. He assumes that the traditional system must have been effective. Many other factors besides the management system may have affected fish populations, including environmental factors, community predation, human population growth, technological change, and pollution. These have not been investigated. Other authors have supported their arguments about the effectiveness of folk management rules by gathering quantitative data to demonstrate that limited-entry systems result in larger catches for those remaining in the fishery.[22] The favorable effects, however, are due primarily to the fact that the existing stock is reserved for fewer people. Larger catches per capita are not convincing evidence that the rules enhance the stock size. Despite these problems, the senior author has referred to these local-level or folk management systems as effective (Acheson 1989), Christopher Dyer and James McGoodwin refer to "robust systems of folk management" (1994:9), and the theme of Fikret Berkes's 1989 edited volume is "sustainable development." But such statements are little more than professions of faith and do not constitute hard evidence that parametric rules conserve marine resources.

The Maine Lobster Fishery: An Example of Parametric Management

It is difficult to assess the effect of regulations on stocks. The number of biological, climatological, political, and cultural factors is so vast that controlled comparisons are virtually impossible. For this reason, it is difficult to demonstrate the superiority of parametric management over any other approach. There are some case studies, however, that do buttress the case for parametric management. One is the Maine lobster industry, with which we have been working for over two decades.

In the Maine lobster fishery, management has always been parametric in that emphasis has been on regulating how people fish rather than how many fish are caught. Since the 1880s, lobster management in Maine has depended on regulations to protect the breeding stock and increase the number of eggs in the water. These have taken the form of size regulations and prohibitions on taking female lobsters with eggs (Acheson 1988:138–141, 1989, 1993). There is also a law that lobsters may be taken only by traps, which must be equipped with escape vents to allow small lobsters to escape. It is illegal to drag for lobsters using trawls, since, while traps are environmentally benign, trawls are unselective, mangle lobsters, and damage the bottom. In the entire history of the industry, there have been no laws to limit the number of lobsters that can be caught by an individual or in aggregate, nor are there any limits on the number of boats or licenses.

In the Maine lobster fishery, catches have fluctuated greatly over the past 120 years. From 1880 to the present, annual Maine lobster catches averaged about 20 million pounds. There have been two unusual periods: the period between World War I and the beginning of World War II, when the catch was only 5 to 7 million pounds, and the period from 1989 to the present, when lobster catches have hovered around 30 million pounds. In 1994 the catch was 38 million pounds, an all-time record (Maine Department of Marine Resources 1995).

Enough good data have been collected on catches, numbers of boats, traps, temperature changes, changes in regulations, and illegal activity that it is possible to examine all of the hypotheses proposed by biologists and members of the industry concerning the changes observed in catches. The results have been reported in another essay (Acheson and Steneck 1995). While the data from that study cannot be reported here due to

space limitations, some of the findings of this study are important for our purposes.

Explanations of Biologists and Fishers

First, our analysis of time-series data on catches and effort showed that the variations in catches cannot be explained in terms of stock-recruitment models so favored by scientists. Such models would lead us to predict that periods of low catches are associated with large amounts of effort that damaged the breeding stock, and that high catches can be explained in terms of low, or at least controlled, effort. Quite the opposite is the case. In the 1920s and 1930s, when catches were at their lowest, effort was very low as well. In 1931, for example, there were only 2,800 fishers who used 168,000 traps to produce 5.3 million pounds of lobster. By way of contrast, the record-high catches of the 1990s were produced by very high levels of effort. In 1994, 38 million pounds of lobster were caught in Maine by 6,503 license holders using a record nearly 2.4 million traps (Maine Department of Marine Resources 1995). Those traps were more efficient than numbers alone would indicate, due to changes in technology. For the 25 years we have been studying the lobster industry, fisheries biologists have argued that the excess effort was leading the fishery to imminent collapse. That has not happened. We have concluded that the theory has little predictive value.

The favorite hypotheses of the fishing industry will not stand up under scrutiny either.[23] In the 1930s, the low catches were explained in terms of low ex-vessel prices. That is, prices were so low that a large number of people were driven from the industry, and the small number who remained could not produce large catches. In fact, catches were low, but prices were not very low in terms of constant U.S. dollars (Acheson 1992). The real problem was a greatly diminished stock of lobsters, as is indicated by both low total catches and low catch per unit of effort.

Fishers now explain the low catches of the interwar years in terms of what they call the poverty gauge hypothesis (Acheson 1992). That is, the legal minimum size was so large in the early decades of the century that a very high percentage of all lobsters were illegal, which resulted in low catches. If this is true, then catches should have gone down dramatically in 1907, when the legal gauge was increased, making a large number of lobsters illegal. Conversely, catches should have jumped upward in 1915 and 1933, when the legal minimum size was reduced greatly. None of these changes in catches occurred (Acheson and Steneck 1995).

The most popular explanation of fishers for the boom of the 1990s is community predation. They argue that big cod and haddock eat many little lobsters, and since the stocks of these groundfish are at all-time lows, predation on lobster is reduced, resulting in larger catches. However, the evidence is that cod and haddock do not eat an unusually large number of lobsters. In addition, there are a number of other species whose stocks are large that eat as many lobsters as do groundfish, such as sculpin. Moreover, if this hypothesis were true, one would be able to observe an inverse correlation between lobster and cod stocks—allowing for some delay for animals to reach maturity. No such correlation exists (Acheson and Steneck 1995:17–19).

What is most significant about the hypotheses proposed by biologists and lobster fishers is that, true to form, the biologists tend to explain changes in catches in terms of effort; the fishers in terms of environmental, legal, and economic factors.

Parametric Factors Influencing Lobster Catches

What did produce the bust of the interwar years and the boom of the 1990s? Our research on historical data indicate two factors are important: water temperature and parametric regulations.

Water temperature controls a number of important biological processes in lobsters, including molting, growth rates, feeding activity, breeding, and larval settlement. Our data demonstrate that the latter function is the most important where population variations are concerned. Larval lobsters float through the water column after hatching and then settle on the bottom, if temperature conditions are correct. Our statistical data indicate that recruitment of lobsters is correlated with years of temperatures favorable to larval settlement (over 15 degrees Celsius). That is, the bust of the 1920s and 1930s is associated with low water temperatures, the boom of the 1990s with favorable temperatures (Acheson and Steneck 1995).

From the time regulations went into effect to the present, management has been based on varying kinds of size limits and protection of gravid females. In the early decades of the century, however, these regulations were largely ineffective, due to massive violations of the law. It was common during this period for fishermen to keep small lobsters both for home consumption and for sale to those involved in the huge "short lobster trade" (Crie 1932–33). Perhaps worst of all, it was far from uncommon for people to scrub the eggs off gravid females so they could be sold. It is always difficult to get exact data on the amount of illegal activity. However, it is clear that millions of small lobsters were taken before they had a chance to breed once, and the eggs were scrubbed off many females that did manage to survive to breeding size. The commissioner of sea and shore fisheries was so convinced that the massive amount of illegal activity was destroying the industry

that he took unusual political risks to stop it (Acheson 1992:157). His efforts, unfortunately, were in vain. By the 1930s catches had fallen to the point where large numbers of fishermen left the industry (Judd 1988:619).

The magnitude of the disaster drove home the need for conservation and an end to illegal activity. From the early 1930s to the present, support for conservation and law enforcement grew. In the industry at present, conservation regulations are almost universally obeyed. Violators of the law find themselves in trouble not only with the wardens but with large numbers of their fellow fishermen as well (Acheson 1988:90).

The growth of this conservation ethic resulted in political support for a number of unusual conservation laws. In 1933, the legislature was able to pass a double-gauge law—a controversial measure that never would have received much industry support in more normal times.[24] It is still in force. In 1951, the "V-notch" law went into effect. Fishermen who catch a "berried" female (a female with eggs) may voluntarily cut a notch in her tail before they return her to the water. That female may never be legally taken as long as the notch is visible. This program has received almost universal industry support, with the result that there are literally millions of V-notched lobsters—proven breeding stock—in the Gulf of Maine (Acheson 1993:76), a testament to industry support of conservation.[25]

In 1982, the industry supported a law requiring escape vents on all traps to lower mortality by allowing undersized lobsters to escape. In 1993, the industry fought hard to obtain compromise legislation that would prevent the abolition of the V-notch law and the double-gauge measure—laws the industry is convinced are critically important conservation devices (Acheson 1993). In the spring of 1995, industry leaders supported legislation to divide the coast into small units and allow people in the industry to take a strong role in managing them. This legislation would never have passed but for the strong support of industry leaders. These legal measures have undoubtedly played a role in producing the boom of the 1990s, although the magnitude of their effect is still being debated.[26]

The case of the Maine lobster fishery buttresses the idea that preserving basic biological processes is the secret to maintaining the health of stocks. Catches fell when temperatures were not favorable and when regulations to preserve small lobsters and breeding stock were violated en mass. But the fact that water temperature plays such an important role in influencing catches means that some critical variables cannot be controlled. We suspect this may be the case in all fisheries.

The Case for Parametric Management

The problems facing the world's fisheries suggest that a different approach to management is overdue. Numerical management, as it is currently practiced, is not working well. We are convinced that the major problem lies in the concepts used.

We would argue that numerical approaches to management be replaced with parametric management, which is more appropriate for fisheries, given their chaotic nature. We are proposing that fisheries be managed through rules on how fishing is done in relatively small areas, to maintain regular biological processes, rather than by attempting to control how much is caught, in an attempt to achieve MSY over the entire range of the stock, as is currently done. Factors such as growth rates, spawning potential, migration routes, predation patterns, and nursery grounds remain relatively stable over time. These are the parameters of our computer model, and as long as they remain stable, populations of fish fluctuate only within certain limits. These parameters can be maintained by rules on technology, time, and location and by protecting animals in certain periods of their life cycles. To be sure, such a program would not result in stable or even predictable catches, but we believe it would avoid the kinds of stock failures and disasters being experienced in so many fisheries at present. That may be all we can reasonably expect to accomplish.

Several aspects of the parametric approach should be stressed. First, the primary advantages of the parametric approach are that it lowers costs of obtaining the information, which ultimately lowers enforcement costs and results in the generation of effective institutions. Parametric management seeks to preserve regular biological processes, which can be observed by humans and do not change much, if at all. This means that knowledge about these biological processes can be gathered at reasonable cost and that knowledge, once gained, should last a considerable time. When people generate rules to maintain these essential biological processes, rules they believe are effective and see as realistic or in their best interest, they can be expected to support them. This should result in fewer infractions and ultimately more effective conservation of the resource.

The numerical approach focuses attention on controlling mortality on target species. This, we argue, is the fatal flaw. It demands so much information that these management regimes are impractical. The lack of effectiveness of such systems is noted by fishers, who have a strong motivation to become free riders, thereby raising enforcement costs and making the development of effective rules costly, if not impossible.

Furthermore, while in a small-scale tribal society local people can develop rules to manage small areas with no involvement of the government, if parametric management is to be used in modern industrial fisheries, a hierarchical approach to regulation must be used. Some biological factors are characteristic of the species over its entire range (e.g., spawning potential); others are very localized (e.g., habitat). Thus, some regulations will be required to affect the fisheries system on a large scale. Others can be tailored to affect smaller-scale events and processes. Different levels of government must be involved in each. Failure to match biological and social scales can result in problems. For example, when administrative units are too small, people in one unit may have no incentive to conserve uncatchable juveniles who migrate to other areas where they are caught as adults.

Where possible, management should be handled by small-scale units. These have two advantages. Management of small units eases the problems of obtaining information on biological processes, since it is easier to learn the intricacies of a small zone than a large one. Local-level management would presumably be more able to frame rules to fit local conditions in ways that take into account local practices and norms. This, in turn, should result in a higher degree of political support. This is not to suggest, however, that there are no biological phenomena of the stocks and aspects of the fisheries that are not general, and demand management on a very large scale.

Finally, there are a number of fisheries that have been managed by local-level political units using a parametric approach (see Figure 3). The approach we are advocating is scarcely untried. Moreover, many observers of such folk management systems are convinced of their effectiveness; analysis of the data from the Maine lobster industry supports this contention. The idea that we in modern countries have much to learn about resource management from third-world societies does not easily suggest itself to scientists and administrators. However, we suggest there is a good deal to be learned and that such societies may have discovered the key to solving very serious problems with the world's major fisheries.

Notes

Acknowledgments. The research on which this essay is based was done between 1987 and 1993 as part of the University of Maine Chaos Project, sponsored by the University of Maine and the University of New Hampshire Sea Grant Program. A number of papers have resulted from this project, including Acheson 1995; Wilson and Dickie 1995; Wilson and Kleban 1992; and Wilson et al. 1991a, 1991b. Both of the authors hold joint appointments in the Center for Marine Studies at the University of Maine, and both have been employed by the National Marine Fisheries Service.

1. Austin 1992; Bencivenga 1991; McGoodwin 1990:1–4; *New York Times* 1992; Walsh 1991.

2. Finlayson 1991; Smith 1990; Wilson and Kleban 1992. The journal *Maritime Anthropological Studies (MAST)* is now unfortunately defunct. In its short life, a large amount of good maritime anthropology appeared in its pages.

3. Parametric management is not radically new. Rather it modifies and extends a number of disparate solutions that have been proposed to cure the problem of fisheries in recent years. Some biologists have advocated ecosystem approaches, while others favor multispecies management of fisheries (Kerr and Ryder 1989). Some social scientists favor self-governance (comanagement or local-level management) of fisheries. The parametric approach incorporates parts of all of these ideas. Most important, fishing communities in large parts of the world manage their fisheries in ways that are congruent with this approach. Resource users discovered the essence of the parametric approach long before we did.

4. Fishing effort refers to the physical inputs in the fishing productive system. It is usually conceived in terms of numbers of people or boats exploiting a given stock. It is generally conceded to be a sloppy term. In economics as a whole, the relationship between physical inputs and output is expressed in terms of production functions. A key concept is that of an isoquant: the amount of output that can be produced by varying combinations of physical inputs. Implicit in the idea of an isoquant is the notion that inputs can be substituted for each other. Fishing effort does not include the idea of substitutability (that people can be substituted for boats).

5. Such policies include quotas or other measures evaluated in terms of fishing mortality; see Rosenberg et al. 1993.

6. There are a few cases that buttress the stock-recruitment model of fisheries. During World War I and World War II, when fishing effort decreased, the stocks went up. We might also mention the case of the striped bass and the salmon stocks of the Frazer River and Alaska. However, a large number of factors other than effort could explain an increase in these stocks during those periods.

7. Garrett Hardin, perhaps the most widely read common property theorist, argues that governments probably will have to act in highly autocratic fashions to protect resources (Hardin 1968, 1977).

8. Acheson 1989; Anderson and Simmons 1993; Feeny et al. 1990; Hardin 1968; McCay and Acheson 1987.

9. Figure 2 contains only a few of the many cases of fisheries under scientific management. We could have included dozens of additional cases.

10. Two kinds of difficulties were encountered in categorizing societies and placing them in Figure 2 or Figure 3. The first concerns the level of control by governments, scientists, and people at the local level. Most of the fisheries in the societies in Figure 2 are managed by the officials of central governments with the help of scientists. There are fisheries in modern industrial countries, however, where the fishing industry has had a very strong influence on the regulations employed, including the Maine lobster industry (Case 5) and the Lofoten groundfishery (Case 6). These are more cases of

what Pinkerton (1989) calls "co-management" than instances of "scientific" management by a central government.

Most of the societies in Figure 3 are cases where management rules are generated and enforced at the level of the local fishing community. Some of the societies, however, have strong control by governments, even though the management techniques have not been developed by scientists. Tokugawa Japan (Case 9), for example, exhibited strong top-down control even though no scientists were involved. It is scarcely a quintessential case of folk management.

Second, in an era of rapid change, traditional ways of managing fisheries are breaking down, and many governments of third-world countries are superimposing top-down management schemes on local communities regardless of the state of the folk management system. Thus, a society that might be placed in Figure 3 at one point in time might well be placed in Figure 2 at another. Figure 3 contains cases in which fisheries management rules were generated by local people, or at least by nonscientists, at the time the ethnography was written.

11. "Riparian rights" refers to kinds of ownership rights over areas or resources in oceans, lakes, or rivers. The exact bundle of rights such owners have varies considerably from society to society. In worldwide perspective, riparian rights are very common (Acheson 1981:280–281; Durrenberger and Palsson 1987). Fikret Berkes, a very knowledgeable observer, says that fisheries "are almost never truly open-access" (Berkes 1985:204).

12. All of the societies in Figure 3 have fisheries that were not under scientific management at the time the ethnography was written. They are all cases in which the ethnographer stated that rules existed to control the resources in some way.

Moreover, the cases reported were not selected by a random sample. The ethnography on most tribal and peasant societies typically contains little on the rules used to regulate fisheries. We had to select cases where solid data were available.

We have been accused of being biased toward successful cases in our selection of third-world fisheries. Since we did not select the cases using a random sample, we have little defense. However, the point is not that these rules always succeed, but that the kind of rules chosen in fisheries where the scientific approach to management is absent have certain characteristics. They can and often do work well.

13. In the ethnography, there are several instances in which it is expected that people will take only the amount of resources they can consume. However, an emphasis on conservation, which motivates individuals to voluntarily restrict effort, is very different from an enforced rule specifying how much can be taken by an individual or community as a whole.

14. Recruitment refers to the number of adult fish produced several years hence (see Daan et al. 1990; Hall 1988).

15. Even if fisheries do not prove to be chaotic, they are certainly complex. This complexity alone will make prediction very difficult.

16. Wilson et al. 1991a, 1991b and Wilson and Kleban 1992.

17. For example, estimates on natural mortality on lobster stocks range from 2 percent to 30 percent.

18. A "free rider" is able to take advantage of benefits provided by other people and does not have to pay for them (see Acheson 1994:16). Olsen (1965) defines a "public" or "collective" good as any set of rules that help a community to achieve a goal that cannot be achieved by individual effort. They are created only under unusual conditions in which special incentives apply.

19. This is not to suggest that high enforcement costs alone are responsible for the breakdown of conservation institutions. (See McGoodwin 1994 for a case in which a number of other factors are involved in the dissolution of a folk management system.) A good many factors are necessary for institutions to be "crafted." Among the most essential conditions are the ability to monitor and sanction those who violate rules. Numerical management, which demands a huge amount of quantitative data on catch, makes monitoring prohibitively costly. The results are marked problems in maintaining fisheries management regulations.

Social scientists are beginning to ask about the conditions under which institutions to manage resources are generated and break down (Acheson 1994; Anderson and Simmons 1993; Dyer and McGoodwin 1994:9; Ensminger and Ruttan 1991; Ostrom 1992). This body of literature borrows heavily from institutional economics and rational choice theory.

20. Acheson 1989, 1994:9–11; Anderson and Simmons 1993; Berkes 1985, 1989; Dyer and McGoodwin 1994; Johannes 1978; McCay and Acheson 1987; Ruddle and Johannes 1985.

21. Berkes 1987:84; Foster and Poggie 1993; and Klee 1980:253–257.

22. Acheson 1988: app. 1; Dyer and Leard 1994.

23. These explanations for the marked variations in catches have been offered by bright and experienced fishers and biologists. The fact that they are widely accepted reveals something about the social construction of reality.

24. The double-gauge law made it illegal to take lobsters under $3\frac{1}{8}$ inches and over $4\frac{1}{2}$ inches in order to protect small lobsters and large lobsters, which are proven breeding stock. Maine is the only jurisdiction in the world to have a double-gauge law.

25. Both informal norms and formal laws promoted by the industry control lobster fishing practices (Acheson 1993). Palmer makes the case that informal norms alone could not conserve the resources. Legislation is necessary (Palmer 1994).

26. Acheson and Steneck 1995; Bayer et al. 1989; and Fogarty 1995.

References Cited

Acheson, James M.
1981 Anthropology of Fishing. Annual Review of Anthropology 10:275–316.
1984 Government Regulation and Exploitive Capacity: The Case of the New England Groundfishery. Human Organization 43:319–329.
1988 The Lobster Gangs of Maine. Hanover: New England University Press.
1989 Management of Common-Property Resources. *In* Economic Anthropology. Stuart Plattner, ed. Pp. 351–378. Stanford: Stanford University Press.

1992 The Maine Lobster Industry. *In* Climate Variability, Climate Change and Fisheries. Michael Glantz, ed. Pp. 147–165. Cambridge: Cambridge University Press.

1993 Capturing the Commons: Legal and Illegal Strategies. *In* The Political Economy of Customs and Culture: Informal Solutions to the Commons Problem. Terry L. Anderson and Randy T. Simmons, eds. Pp. 69–84. Lanham, MD: Rowman and Littlefield.

1994 Welcome to Nobel Country: An Overview of Institutional Economics. *In* Anthropology and Institutional Economics. Monographs in Economic Anthropology, 12. James M. Acheson, ed. Pp. 3–42. Lanham, MD: University Press of America.

1995 Environmental Protection, Fisheries Management and the Theory of Chaos. *In* Improving Interactions between Coastal Science and Policy. National Research Council, U.S. Ocean Studies Board. Pp. 155–160. Washington, DC: National Academy Press.

Acheson, James M., and Robert Steneck

1995 Bust and Boom in the Maine Lobster Industry. Unpublished MS.

Akimichi, Tomoya

1981 Perception and Function: Traditional Resource Management in Three Pacific Islands. Resource Management and Optimization 4:361–378.

Akimichi, Tomoya, and Kenneth Ruddle

1984 The Historical Development of Territorial Rights and Fishery Regulations in Okinawan Inshore Waters. *In* Maritime Institutions in the Western Pacific. Kenneth Ruddle and Tomoya Akimichi, eds. Pp. 37–88. Osaka: National Museum of Ethnology.

Alexander, Paul

1980 Sea Tenure in Southern Sri Lanka. *In* Maritime Adaptations: Essays on Contemporary Fishing Communities. Alexander Spoehr, ed. Pp. 91–112. Pittsburgh: University of Pittsburgh Press.

Anderson, Lee G.

1992 Consideration of the Potential Use of Individual Transferable Quotas in U.S. Fisheries. The National ITQ Study Report 1:1–71.

Anderson, Terry L., and Randy Simmons

1993 The Political Economy of Customs and Culture: Informal Solutions to the Commons Problem. Lanham, MD: Rowman and Littlefield.

Austin, Phyllis

1992 Who Killed Maine's Multi-Million Dollar Fishery? Maine Times, February 14: 2.

Baines, G. B. K.

1989 Traditional Resource Management in the Melanesian South Pacific: A Development Dilemma. *In* Common Property Resources: Ecology and Community-Based Sustainable Development. Fikret Berkes, ed. Pp. 273–296. London: Belhaven.

Barinaga, Marcia

1995 New Study Provides Some Good News for Fisheries. Science 269:1043.

Bayer, Robert, Peter Daniels, and Cheryl Waltz

1989 Egg Production of V-Notch American Lobster along Coastal Maine. Journal of Crustacean Biology 9:77–82.

Belcher, William

1993 Personal communication.

Bencivenga, Jim

1991 New England's Fishery in Decline. Christian Science Monitor 83 (July 26): 3.

Berkes, Fikret

1985 Fishermen and the Tragedy of the Commons. Environmental Conservation 12(5):199–205.

1986 Marine Inshore Fishery Management in Turkey. *In* Proceedings of the Conference on Common Property Resource Management. Pp. 63–83. National Research Council. Washington, DC: National Academy Press.

1987 Common Property Resource Management and Cree Indian Fisheries in Subarctic Canada. *In* The Question of the Commons: The Culture and Ecology of Communal Resources. Bonnie J. McCay and James M. Acheson, eds. Pp. 66–91. Tucson: University of Arizona Press.

Berkes, Fikret, ed.

1989 Common Property Resources: Ecology and Community-Based Sustainable Development. London: Belhaven.

Bishop, Charles

1970 The Emergence of Hunting Territories among the Northern Ojibwa. Ethnology 9(1):1–15.

Brightman, Robert

1987 Conservation and Resource Depletion: The Case of the Boreal Forest Algonquins. *In* The Question of the Commons: The Culture and Ecology of Communal Resources. Bonnie J. McCay and James M. Acheson, eds. Pp. 121–141. Tucson: University of Arizona Press.

Carrier, James

1987 Marine Tenure in Papua New Guinea. *In* The Question of the Commons: The Culture and Ecology of Communal Resources. Bonnie J. McCay and James M. Acheson, eds. Pp. 142–167. Tucson: University of Arizona Press.

Crie, Horatio

1932–33 Correspondence of the Commissioner of Sea and Shore Fisheries. Augusta: Maine State Archives.

Cushing, D. H.

1977 The Problems of Stock Recruitment. *In* Fish Population Dynamics. J. A. Gulland, ed. Pp. 116–133. London: John Wiley.

1988 The Provident Sea. Cambridge: Cambridge University Press.

Daan, Nils, P. J. Bromley, J. R. G. Hislop, and N. A. Nielsen

1990 Ecology of North Sea Fish. Netherlands Journal of Sea Research 26:343–386.

Dewar, Margaret

1983 Industry in Trouble: The Federal Government and the New England Fisheries. Philadelphia: Temple University Press.

Durrenberger, Paul, and Gisli Palsson

1987 Ownership at Sea Fishing Territories and Access to Sea Resources. American Ethnologist 14:508–522.

1995 Personal communication.

Dyer, Christopher L., and Richard L. Leard

1994 Folk Management in the Oyster Fishery of the U.S. Gulf of Mexico. *In* Folk Management in the World's Fisheries. Christopher L. Dyer and James R. McGoodwin, eds. Pp. 55–89. Niwot: University Press of Colorado.

Dyer, Christopher L., and James R. McGoodwin, eds.
1994 Folk Management in the World's Fisheries. Niwot: University Press of Colorado.

Ensminger, Jean, and Andrew Ruttan
1991 The Political Economy of Changing Property Rights: Dismantling a Pastoral Commons. American Ethnologist 18:683–699.

Feeny, David, Fikret Berkes, Bonnie J. McCay, and James M. Acheson
1990 The Tragedy of the Commons: Twenty-Two Years Later. Human Ecology 18(1):1–19.

Finlayson, Chris
1991 Notes on Chaos in Fisheries Management. Maritime Anthropological Studies 4(1):91–97.

Foster, Kevin B., and John J. Poggie Jr.
1993 Customary Marine Tenure and Mariculture Management in Outlying Communities of Pohnpei State, Federated States of Micronesia. Ocean and Coastal Management 20:1–22.

Friedrich, Paul
1988 Eerie Chaos and Eerier Order. Journal of Anthropological Research 44:435–447.

Gadgil, Madhav
1985 Social Restraints on Resource Utilization: The Indian Experience. *In* Culture and Conservation: The Human Dimension in Environmental Planning. J. A. McNeeley and D. Pitt, eds. Pp 135–154. Dublin: Croom Helm.

Gleick, James
1987 Chaos: Making a New Science. New York: Viking.

Hall, Charles
1988 An Assessment of Several of the Historically Most Influential Theoretical Models Used in Ecology and of the Data Provided in Their Support. Ecological Modelling 43:5–31.

Han, Sang-Bok
1972 Socio-economic Organization and Change in Korean Fishing Villages: A Comparative Study of Three Fishing Communities. Ph.D. dissertation, Michigan State University. Ann Arbor, MI: University Microfilms.

Hardin, Garrett
1968 The Tragedy of the Commons. Science 162:1243–1248.
1977 Living on a Lifeboat. *In* Managing the Commons. Garrett Hardin and John Baden, eds. Pp. 261–279. San Francisco: W. H. Freeman.

Hastings, Alan, and Kevin Higgins
1994 Persistence of Transients in Spatially Structured Ecological Models. Science 263:1133–1136.

Holling, C. S.
1994 Engineering Resilience versus Ecological Resilience. Paper presented to the Working Group on Ecosystems and Property Rights. Beijer Institute, Swedish Academy of Sciences, Stockholm.

Jentoft, Svein, and Trond Kristoffersen
1989 Fishermen's Co-management: The Case of the Lofoten Fishery. Human Organization 48:355–365.

Johannes, R. E.
1978 Traditional Marine Conservation Methods in Oceania and Their Demise. *In* Annual Review of Ecology and Systematics, 9. R. Johnson, ed. Pp. 349–364. Palo Alto: Annual Reviews.
1981 Worlds of the Lagoon: Fishing and Marine Life in Palau District of Micronesia. Berkeley: University of California Press.

Judd, Richard W.
1988 Saving the Fisherman as Well as the Fish: Conservation and Commercial Rivalry in Maine's Lobster Industry, 1872–1933. Business History Review 62:596–625.

Kalland, Arne
1984 Sea Tenure in Tokugawa Japan: The Case of the Fukuoka Domain. *In* Maritime Institutions in the Western Pacific. Kenneth Ruddle and Tomoya Akimichi, eds. Pp. 11–36. Osaka: National Museum of Ethnology.

Kerr, S. R., and R. A. Ryder
1989 Current Approaches to Multispecies Analyses of Marine Fisheries. Canadian Journal of Fisheries and Aquatic Sciences 46:528–534.

Klee, Gary
1980 Oceania. *In* World Systems of Traditional Resource Management. Gary Klee, ed. Pp. 245–281. New York: John Wiley.

Leveil, Dominique P., and Benjamin Orlove
1990 Local Control of Aquatic Resources: Community and Ecology in Lake Titicaca, Peru. American Anthropologist 92:362–382.

Ludwig, Donald, Ray Hilborn, and Carl Walters
1993 Uncertainty, Resource Exploitation and Conservation: Lessons from History. Science 260:17–36.

Maine Department of Marine Resources
1995 Summary of the Maine Lobster Fishery Statistics. Augusta, ME: Department of Marine Resources.

Martin, K. O.
1979 Play by the Rules or Don't Play at All. *In* North Atlantic Maritime Cultures. Raoul Andersen, ed. Pp. 277–298. The Hague: Mouton.

McCay, Bonnie J., and James M. Acheson
1987 Human Ecology of the Commons. *In* The Question of the Commons: The Culture and Ecology of Communal Resources. Bonnie J. McCay and James M. Acheson, eds. Pp. 1–34. Tucson: University of Arizona Press.

McGoodwin, James R.
1987 Mexico's Conflictual Inshore Pacific Fisheries: Problem Analysis and Policy Recommendations. Human Organization 46:221–231.
1990 Crisis in the World's Fisheries. Stanford: Stanford University Press.
1994 "Nowadays, Nobody Has Any Respect": The Demise of Folk Management in a Rural Mexican Fishery. *In* Folk Management in the World's Fisheries. Christopher L. Dyer and James R. McGoodwin, eds. Pp. 43–54. Niwot: University Press of Colorado.

Miller, David
1989 The Evolution of Mexico's Spiny Lobster Fishery. *In* Common Property Resources: Ecology and Community-Based Sustainable Development. Fikret Berkes, ed. Pp. 185–198. London: Belhaven.

Murton, Brian J.
1980 South Asia. *In* World Systems of Traditional Resource Management. Gary Klee, ed. Pp. 67–99. New York: John Wiley.

Nelson, Richard K.
1982 A Conservation Ethic and Environment: The Koyukon of Alaska. *In* Resource Managers: North American and Australian Hunter-Gatherers. Nancy Williams, ed. Pp. 211–228. Boulder: Westview.

New York Times
1992 Plenty of Fish in the Sea? Not Any More. March 25: A14.

Nietschmann, Bernard
1985 Torres Strait Islander Sea Resource Management and Sea Rights. *In* The Traditional Knowledge and Management of Coastal Systems in Asia and the Pacific. Kenneth Ruddle and R. E. Johannes, eds. Pp. 127–154. Jakarta, Indonesia: Regional Office for Science and Technology for Southeast Asia, UNESCO.

Olsen, Mancur
1965 The Logic of Collective Action. Cambridge: Cambridge University Press.

Ostrom, Elinor
1992 Crafting Institutions for Self-Governing Irrigation Systems. San Francisco: ICS Press.

Palmer, Craig
1994 Are Folk Management Practices Models for Formal Regulations? Evidence from the Lobster Fisheries of Newfoundland and Maine. *In* Folk Management in the World's Fisheries. Christopher L. Dyer and James R. McGoodwin, eds. Pp. 237–250. Niwot: University Press of Colorado.

Palsson, Gisli
1994 Enskilment at Sea. Man 29:901–927.

Park, Thomas
1992 Early Trends toward Class Stratification: Chaos, Common Property, and Flood Recession Agriculture. American Anthropologist 94:90–117.

Philippe, P.
1993 Chaos, Population Biology and Epidemiology: Some Research Implications. Human Biology 65:525–546.

Pinkerton, Evelyn
1989 Cooperative Management of Local Fisheries: New Directions for Improved Management and Community Development. Vancouver: University of British Columbia Press.

Robben, Antonius C. G. M.
1994a Conflicting Discourses of Economy and Society in Coastal Brazil. Man 29:875–900.
1994b Personal communication.

Rosenberg, A. A., M. J. Fogarty, M. P. Sissenwine, J. R.
Reddington, and J. G. Shepherd
1993 Achieving Sustainable Use of Renewable Resources. Science 262:828–829.

Rowntree, J., et al.
1984 Fishery Management in the Northern Nile Delta Lakes of Egypt: The Case of Hosha. Food and Agriculture Organization of the United Nations, Studies and Reviews 61:542–555.

Royce, William F.
1989 Managing Alaska's Salmon Fisheries for a Prosperous Future. Fisheries 14(2):8–13.

Ruddle, Kenneth
1989 Solving the Common Property Dilemma: Village Fisheries Rights in Japanese Coastal Waters. *In* Common Property Resources: Ecology and Community-Based Sustainable Development. Fikret Berkes, ed. Pp. 168–184. London: Belhaven.

Ruddle, Kenneth, and R. E. Johannes, eds.
1985 The Traditional Knowledge and Management of Coastal Systems in Asia and the Pacific. Jakarta, Indonesia: Regional Office for Science and Technology for Southeast Asia, UNESCO.

Sherman, Kenneth, and Thomas Laughlin, 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.

Sissenwine, Michael P.
1984 Why Do Fish Populations Vary? *In* Explorations of Marine Communities. R. M. May, ed. Pp. 59–94. Berlin: Springer-Verlag.
1986 Perturbation of a Predator-Controlled Continental Shelf Eco-system. *In* Variability and Management of Large Marine Eco-systems. AAAS Selected Symposium, 99. K. Sherman and L. M. Alexander, eds. Pp. 55–85. Boulder: Westview.

Sissenwine, Michael P., and Pamela Mace
1991 ITQ's in New Zealand: The Era of Fixed Quotas in Perpetuity. Fishery Bulletin 90:147–160.

Smith, M. Estellie
1990 Chaos in Fisheries Management. Maritime Anthropological Studies 3(2):1–13.

Southon, Michael
1989 Competition and Conflict in an Ecuadorian Beach-seine Fishery. Human Organization 48:365–369.

Sullivan, Karl
1987 Open Entry Fishery = Tragedy of the Commons. Fisheries 12:2.

Sutherland, Ann
1986 Economic Success in a Belizean Fishing Village. Boulder: Westview.

Van Ginkel, Robert
1989 Plunderers into Planters: Zeeland Oystermen and the Enclosure of the Marine Commons. *In* Dutch Dilemmas: Anthropologists Look at the Netherlands. Jeremy Boissevain and Jojada Verrips, eds. Pp. 89–105. Assen, the Netherlands: Van Gorcum.

Vondal, Patricia
1987 The Common Swamplands of Southeastern Borneo. *In* The Question of the Commons: The Culture and Ecology of Communal Resources. Bonnie J. McCay and James M. Acheson, eds. Pp. 231–249. Tucson: University of Arizona Press.

Walsh, Mary Williams
1991 Peril for a Fish—and a Way of Life. Los Angeles Times, July 20: A1, A20.

Wieland, Robert
1992 Why People Catch Too Many Fish: A Discussion of Fishing and Economic Incentives. Washington, DC: Center for Marine Conservation.

Williams, Nancy M.
1982 A Boundary to Cross: Observations on Yolngu Boundaries and Permission. *In* Resource Managers: North American and Australian Hunter-Gatherers. Nancy Williams, ed. Pp. 131–153. Boulder: Westview.

Wilson, James A., and Lloyd Dickie
1995 Parametric Management of Fisheries: An Ecosystem-Social Approach. *In* Property Rights in a Social and Ecological Context. Susan Hanna and Mohan Munasinghe, eds. Pp. 153–166. Stockholm: Beijer International Institute of Ecological Economics and the World Bank.

Wilson, James A., and Peter Kleban
1992 Practical Implication of Chaos in Fisheries. Maritime Anthropological Studies 5(1):67–75.

Wilson, James A., John French, Peter Kleban, Susan McKay, and Ralph Townsend
1991a Chaotic Dynamics in a Multiple Species Fishery: A Model of Community Predation. Ecological Modelling 58:303–322.

1991b The Management of Chaotic Fisheries: A Bio-economic Model. *In* Proceedings from Symposium on Multiple Species Fisheries. Michael Sissenwine and Nils Daan, eds. Pp. 287–300. Copenhagen: International Council for the Exploration of the Sea.

Zann, Leon P.
1985 Traditional Management and Conservation of Fisheries in Kiribah and Tuvalu Atolls. *In* The Traditional Knowledge and Management of Coastal Systems in Asia and the Pacific. Kenneth Ruddle and R. E. Johannes, eds. Pp. 53–77. Jakarta, Indonesia: Regional Office for Science and Technology for Southeast Asia, UNESCO.