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Scale and Costs of Fishery Conservation

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Abstract: Observation and measurement of the ocean's ecosystems is difficult and costly. It makes verification of our theories difficult and forces us to engage in collective action based upon often very imperfect concepts of the dynamics of the system. Once we establish the institutions of collective action, however, we adopt 'official' conceptions of system dynamics that define the bounds of individual action. In response, individuals (in both private and public employment) invest in skills, knowledge, capital, technology, business plans, and scientific agendas that fit within those bounds. The self-interest reflected in these investments filters the amount and the quality of private information provided to the public so that it is consistent with the self-interest of the agents who acquire it. If the system being managed is simple and the costs of data collection minor, these impairments are not likely to be significant. Under these circumstances a public, impersonal science body should be able to gather whatever information is necessary for continuing adaptive governance. In a complex system, however, these impairments deprive the governance process of valuable information and reduce the scope for collective adaptation (the set of feasible rules). In these circumstances path dependent lock-in reduces adaptive capacity, contributing thereby to the circumstances for still another tragedy.

Our way out of this dilemma rests in institutional design that is adapted to an understanding of the limits of our ability to monitor, predict and control natural systems. We tend to gravitate towards scientific, institutional, and private arrangements that emphasize the use of quantitative knowledge. We do this because our collective experience elsewhere has taught us that quantitative approaches facilitate the processes of collective action. In the kinds of complex systems found in the ocean, however, the ability to acquire collectively useful quantitative knowledge is limited in ways that are consistent and knowable. At fine ecological and temporal scales the costs of observation generally prevent reasonable quantitative management of the

resource; at broad scales quantitative approaches are impaired by the slow pace at which we can acquire observations of the system. Nevertheless, knowledge of these fine and broad scale aspects of natural systems is important to our adaptive capacity. Persistent reliance upon institutional arrangements keyed to quantitative approaches only tends to blind us to a substantial segment of the natural system, restrict our adaptive capacity, and make us vulnerable to surprises that develop outside the scope of our collective vision. Improving our adaptive capacity, consequently, means matching our institutional designs to the kinds of knowledge we can acquire economically.

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1. Introduction

Many of the lessons we have learned in the ocean fishery commons replicate the lessons we have learned elsewhere in terrestrial and other commons (Defeo and Castilla 2005; Acheson 2003; Netting 1981; Ostrom 2007). However, the very poor state of the world's fisheries is strong evidence of the difficulty we have had making those lessons work in the ocean. What appears to distinguish the ocean commons in particular is the problem we encounter finding rules that are able to accomplish the goals of our collective action, that is rules restraining fishing in a way that actually sustains the fishery and the ecosystem. Finding appropriate rules may appear to be a purely technical question, the optimal rate of fishing mortality or the right mesh size of nets—but our uncertainty about ocean dynamics has important implications for the kinds of institutions we tend to develop for its governance and, consequently, the scope and nature of the technical rules that are feasible.

Our ability to predict changes in ocean systems is limited and consistently biased by the costs of acquiring and analyzing data about the ocean. That bias affects the science we employ, the choices we make as individuals, and the choices we make when we create institutions for the governance of our common activities. These choices set boundaries on our collective ability to adapt and usually send us down a path that makes further adaptation increasingly difficult (Stigler 1971; Diamond 2000; Costanza et al. 2001). The direction of that path and the extent to which it constrains our adaptive scope is determined importantly by the initial design of the institutions governing our collective action. Once in place, people (private individuals, corporations, scientists and agents of the government) adapt to the rules set by those institutions. These groups invest in skills, capital, technology and scientific programs consistent with the social expectations embedded in the current rule set and they learn to engage in political activity that reinforces the value of those investments. This individual action strengthens the biases of the initial institutional design, constraining further the collective ability to adapt. As a result the very basic problem we face is how we might design institutions that are able to align individual behavior with socially desirable outcomes, and at the same time avoid the path dependency that locks us into an ill-conceived adaptation and still another tragedy of the commons. Until very recently, we did not even suspect that our activities might have a deleterious effect on the functioning of the ocean's natural systems. In the last hundred years or so, however, our harvesting technology, the market value of fish, and our ability to store and ship the ocean's products have all dramatically increased our impact on the ocean (Jackson et al. 2001; Berkes et al. 2006). Over the same time our understanding of what we can do to mitigate that impact has grown much less rapidly. Our difficulty learning about the ocean arises largely because we are not at home in the ocean. Almost all of our observation of the ocean is indirect, episodic, and expensive. Further, as is becoming apparent, the ocean system itself is much more complex than we imagined. The first public concern that human activity was impacting the ocean in an unfavorable way in both Europe and the United States arose only in the late 1800s (see for example Baird 1883, pp. xi-xiv). It is interesting to consider the methods in which an ocean scientist at this time might have begun the task of addressing this concern: the ocean could be observed easily only on its surface and then only at substantial expense; the inhabitants of the ecosystem would be known only (or principally) as the product of fishing; there would be only the most rudimentary understanding of the interactions of its inhabitants (most of which are known from the contents of the stomachs of what is caught); and there would be no developed theory to guide observation, and any hypotheses developed about ocean processes would be extraordinarily hard to test. Even traditional knowledge would be hard to come by. Fishers, the people who have the most intimate knowledge of the ocean, tend to be secretive. Even when talkative the knowledge they convey is subtle and based upon only the most indirect clues about what might be happening below the surface. The color of the water, the run of tides and current, the way the swells rise and fall, the way waves ripple and break, laborious soundings with lead lines, the behavior of birds, and the occasional breach of fish or whales all accumulate into a hard-won experience that correlates with particular times and places where fish can be caught. This was and is a substantial body of knowledge. But this knowledge is privately held and, most of all, acquired with a particular objective in mind, catching fish, not conserving them. The limited scope of this knowledge mattered little for conservation and generally had only beneficial social consequences so long as the effect of fishing was trivial and overwhelmed by the ocean's reproductive capacity. However, as it became obvious that human activities were affecting the ocean, the nature of socially useful knowledge changed. The social problem of conserving fish required not only the particularistic knowledge that fishers find so valuable, but also the broader-scale system level ecological knowledge about the impact of human activity on habitat, the abundance of each stock, and the overall health of the system.

In the absence of foresight conferred by an understanding of causality, human adaptation is not too different from biological evolution. When collective action is taken, it is generally driven by conflicts over access to the resource (Knight 1992; Acheson 2003) and often lands upon effective solutions only by coincidence. Even then the adaptations that do occur are likely to be made with regard to specific components of the system (e.g., a fishery for a particular species) and their durability remains vulnerable to the absence of sustainable adaptations elsewhere in the system. That vulnerability might lead to a decline in abundance. Somewhat surprisingly, it also might lead to hyper-abundance due to the extirpation of a significant predator(s) or the removal of some other significant ecological restraint. The lobster fishery in the Northwest Atlantic, for example, has been sustained very well since the end of World War II, probably due to good conservation practices. Since the late eighties, however, it has enjoyed an unprecedented boom in abundance and landed value (Maine DMR 2006). That current abundance is probably best attributed to the erosion of ecological structure in the remaining part of the system probably the loss of large finfish predators (Steneck 1997; Myers and Worm 2003). Ironically, that same loss of structure may also be a serious threat to the sustainability of the lobster fishery, and to any other well managed fishery for that matter. In the future that loss of structure might just as easily lead to a collapse of the lobster population and a bloom of jellyfish or something else even further down the food chain (Pauly et al. 1998). These kinds of broader scale system level effects from fishing are not likely to be solved by the normal give and take of single species regulatory action. Consequently, if we don't consciously undertake collective action to design governing institutions (as opposed to allowing their incremental evolution through the normal give and take of individual and group interests), we are likely to bump into sustainable adaptations only by accident. Whether we expect these kinds of 'partial system' solutions to add up to durable system-wide solutions depends principally upon our view of the impact of our activities on the natural world, basically our mental model of causality in the ocean system.

2. Two views of the ocean system

There are essentially two paradigmatic views about causality held by scientists and also by users of the resource. These views are not mutually exclusive, at least to most people's thinking. Most biologists tend to take a fairly eclectic theoretical approach and, depending on their needs at the moment, use one or the other or both of these perspectives. In my experience the same holds, more or less, for fishermen and managers.

One view is a formal, species specific, deterministic perspective that follows a more or less classical scientific path. It assumes a complex non-linear biology in which individual stocks are nearly independent components of a broader system.[1]

[1] Fisheries stocks are usually defined as sub-populations of larger populations of the same species.

It views the long-term structure of causality in the system (really in each of these nearly independent stock units) as stochastically stable ~~i.e~~., if there is a regular relationship between the number of spawning females today and the number of their young that will survive and become adult fish several years later. In the language of economics, it assumes the important ecological relationships are internalized within the bounds of the spawning unit and sees the principal opportunities for human influence within those bounds. It measures its understanding of the system in terms of its ability to predict numerical outcomes at the level of the stock (Cushing 1968). If achieved, this kind of capability can be translated into an understanding of how changes in human activity (e.g.., catching fish) change those numerical outcomes in both the short- and long-run. It follows that this capability should make it possible to choose a level of harvesting activity that will sustain the population/stock. In practice, however, it is almost always the case that there is no known long-run relationship between current and future stock size. As a result, a conservative version of optimal short-run harvesting (i.e., maximization of yield-per-recruit[2]) is assumed to be consistent with sustainability of the stock (Beverton 1998). Implicit in this perspective is the idea that conservative treatment of each stock will add up to conservative treatment of the system. Basically, the notion is that each stock can be treated as an independent entity and both its short- and long-run abundance can be manipulated. This can be done because the proximate (i.e., the immediate) causes of abundance are stable and knowable. If this is the case, policies that seek solutions at the level of individual species can proceed without fear of vulnerability to system wide events and, most important if they are pursued across a collection of species, can be expected to add up to sustainability for the system as a whole.

The second perspective is also concerned with the effect of human activity on the system and the ways that activity can be altered to promote sustainability. However, the sense that the system may be profitably decomposed into nearly independent stock components with relatively stable causality is absent. Ecological interactions (i.e., outside the domain of an individual stock) are assumed to play a much stronger role in the determination of biological outcomes. Those outcomes are generally seen as strongly contingent upon particular circumstances at particular times and places, that is, long chains of events whose particulars are always changing and lead to continually changing, proximal causalities. Consequently, the expectation about the predictability and the possibility of control over particular biological outcomes for particular stocks is much less than in the classical view. This perspective is probably most consistent with the theory of complex adaptive systems. (Holland 1998; Levin 1999; Gell-Mann 1994).

[2] Defined very briefly, a yield-per-recruit model uses estimates (from surveys or landings or both) of the numbers in a cohort of fish and, given the estimated growth and natural mortality of those fish, generates an estimate of the maximum weight that can be harvested while still maintaining a prescribed spawning biomass.

Fishers find they can usefully predict abundance in the very short term, e.g., the persistence of a year class of fish from year to year, but the long term abundance of any stock has only the most tenuous relationship to the current state of a population or the system. Among scientists, that same disconnect between the specific circumstances of a component of the system today and its state in the future is seen as a function of the ecological complexity arising from the non-linearity of biological processes (Levin 1999). In principle the processes in this kind of system are deterministic and predictable. However, given the rapidity of change in marine systems, the importance of contingency, and the difficulty of observation these processes place significant practical bounds on scientific and collective capabilities. Numerical predictability, as a result, is viewed as possible only in the near-term (when it is mostly a matter of short-term extrapolation rather than causality based prediction); longer-term predictability (which is what is relevant to sustainability) is assumed feasible but only in the sense of maintaining broad ecological processes (rather than species specific numerical outcomes). These perceived limitations on predictability and on the ability to control the system inclines practitioners of this perspective towards policies designed to maintain system wide conditions, e.g., predator-prey relationships, population age structure, and habitat, that determine the patterns and dynamics of the system. There is an assumption that the specific numbers of particular kinds of fish that might result from the maintenance of broad structure, though not subject to prediction, are likely to be consistent with the sustainability of both individual stocks and the system. The principal differences between the classical population and the ecological views come down to the temporal, spatial, and ecological scales at which qualitative understanding, numerical predictability and control, or the ability to influence the system are assumed to be practical. This leads to different ideas about what is necessary for sustainability and, especially in systems that have been seriously eroded by fishing and other human activity, different ideas about policies that might rebuild individual stocks and restore ecological processes. And of course, these lead to different views about the institutional arrangements necessary to achieve those ends.

3. Path dependence and the loss of adaptive capacity

From a purely scientific perspective it is useful to be agnostic about these two perspectives. To preserve the option to explore both perspectives, especially the grey areas that lie between them (or in an entirely different direction), is an appropriate hedge in the face of fundamental uncertainty about system dynamics. Scientific agnosticism, however, is a strategy that can paralyze the will to engage in collective action. Collective action is costly, requiring substantial agreement around a course of action that is likely to produce a reasonable outcome. In the absence of that sense of effectiveness there would never be a basis, other than force, for conscious collective action of any sort (Olson 1971).

The problem we face, however, is that whatever method of restraint we design, we give to individuals certain valuable rights. In fisheries those rights might be open access rights, or limited access rights such as what occurs with license limitations, or an individual quota. With these rights, we simultaneously design a system of private-to-public feedback that helps inform us (collectively) about the impact of human activity on the natural system. This information is often a major determinant of further collective action. This is where we have to be cautious because it is possible, of course, to design a system of rights that provides inadequate feedback, that is, one that seriously misrepresents or obscures our impact on the natural world and, for that reason, impairs our collective ability to learn and adapt. Generally, we can expect any system of rights to lead to the private provision of information to the public consistent with the maintenance or enhancement of the value of those rights. This is the great value of aligning individual rights with social objectives. People adapt. Private investments in knowledge, in capital and in competitive strategies all respond to the opportunities created by these rights. Administrative processes and organization are structured around them, as are scientific agendas, research projects, data collection, and careers. If the initial conception of the system is on the mark and if the design of those rights aligns individual incentives with social objectives, private feedback will be appropriate and consistent with the objectives embedded in the governing institution.

However, in any but the most simple and circumscribed social-ecological system we will always find it impossible to perfectly align private and public actions with the long run sustainability of the system. We simply cannot foresee the future with enough clarity to write rules that account for all possible contingencies. The rules governing the exercise of fishers' rights will always provide them with opportunities, sometimes substantial, sometimes only trivial, that are in conflict with the long-term public interest. Consequently, there will always be a tension between the interests of the individual and the interests of the group. This tension plays-out in the usually emphasized problems of enforcement of rules, but there are subtle, and in the long-run much more important ways that these misalignments affect our adaptive capacity. Two appear to be particularly important. First, to the extent that we are not able to align individual actions with social objectives, the costs of monitoring and enforcement diminish the feasible set of ecologically effective rules. For example, fishers generally know much more about local habitat and other fine scale aspects of the system than managers. As a result fishers are frequently faced with the choice of fishing in times and places that may be profitable, but also destructive of local components of the ecosystem. A broad scale regulatory regime might find it very costly to enforce rules governing such actions. Consequently, rules of this kind are not likely to be included in its feasible set. And fishers will be forced by competitive pressures to take ecologically destructive actions. Similarly, a regulatory regime whose scope was only local might have little or no ability to enforce rules governing the harvest of migratory fish and so would simply exclude such rules from its feasible set. And competitive pressures will force fishers to take ecologically destructive actions at a broad scale. In each of these instances, the mismatch of regulatory and ecological scale can place serious limits on our collective abilities to adapt (Costanza et al. 2001; Scheffer et al. 2003) and, on the other side of the same coin, each instance creates competitive circumstances that force fishers to exploit the opportunities that arise at these unregulated scales (Wilson 2006).

Second, the opportunities provided by the rights individuals possess influence the quality and scope of knowledge they supply to the public. Rights holders can be depended upon to use their political weight to ensure that information enhancing the stream of private value produced by their rights enters the public domain (Stigler 1971; Scott 1993). And, they can be depended upon to do their best to ensure that any information detrimental to the value of those rights will not enter the public domain or will enter only reluctantly or in a biased or incomplete or untimely manner. For example, in the scale mismatch described just above, it is not likely that fishers whose fishing leads to the destruction of local habitat will make a habit of reporting their actions, especially if the broad scale regulatory authority ignores such activity. These kinds of impairments in the flow of information from private to public sources also reduce the scope for collective adaptation.

There are two important institutional design questions that arise because of these impairments. The first concerns how we might avoid or minimize the bias arising from the costliness of observation and enforcement and, consequently, the narrowing of the set of rules useful for collective adaptation. The second, related, problem concerns how we might increase the ecological scope of private information provided to the public process and thereby increase the breadth of our adaptive capacity. Our perception of the likely extent of these limits to collective action and of the appropriate ameliorative response depends upon our mental model of the natural system, especially our sense of the scale and extent of our control (or influence) over biological outcomes. There are two lines of thought about predictability and control in ecological systems that are particularly helpful in this regard. The first is the ideas about ecological scale and temporal dynamics contained in hierarchy theory (O'Neill et al. 1986; Allen and Hoekstra 1992); the other is the sense of contingency and irreversibility from the literature on complex adaptive systems (Holland 1998; Gell-Mann 1994; Levin 1999). Together these understandings generate a sense of the way the characteristics of an ecological system affect the costs of observation and in turn bias our ability to predict and control, or at least influence, natural systems. An appreciation of these limits can help guide our sense of the institutional characteristics that are likely to result in continuing adaptive capacity (or avoidance of its loss).

The relevant ideas from hierarchy theory are summarized in the heuristic diagram in Figure 1. Ecological scale and the scale of temporal dynamics tend to be closely correlated. Populations of short-lived organisms tend to be variable over

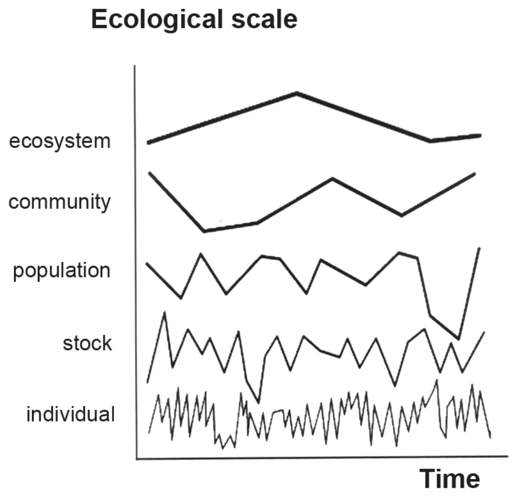

Figure 1: The relative time-steps (rate of variation) at the different scales of an ecosystem. (Sketched from O'Neill, et al., 1986 and Allen and Hoekstra, 1992.)

a relatively short time-span. Populations of larger, longer lived organisms and aggregations such as communities show variation that is slower. For example, stocks of herring (fecund and relatively short-lived) might be expected to vary considerably over a period of several years. Stocks of cod, a much longer lived organism, might be expected to vary at a much slower rate (unless fishing, as is usually the case, compresses the age structure and creates a population of short-lived individuals). The same or similar expectations apply to a hierarchy of individual fish, age cohorts, stocks, populations, communities, and the entire system. Each more aggregated biological entity has a slower time-step than its components. This regularity in complex ecosystems may be viewed as simply a kind of scale dependent inertia. But even so it is an important determinant of the spatial and temporal scale of measurements we can afford to make and the kinds of events to which we can adapt. The theory of complex adaptive systems also adds important insights to an understanding of the limitations to our predictive capabilities. Unlike standard systems theory it emphasizes the role of contingency and history in the determination of ecological outcomes. In a non-linear system the circumstances at a particular time and place may lead to large changes that work their way through the system (Holland 1998). For example, a cohort of fish larvae may (or may not) encounter just the right water temperatures, appropriately sized food, lack of predators etc., so that large numbers survive (or don't) and become the foundation for a strong (or weak or non-existent) year class. Given that these kinds of contingent events occur frequently (and the smaller the organism, generally the more frequent) our ability to predict over an organism's entire life span is very limited. It has, for example, been notoriously difficult to arrive at good quantitative predictions of recruitment (intergenerational changes in the abundance of a particular stock) because the early stages of a fish's life are so filled with contingent events and surprise. As fish grow and approach maturity the frequency of the life threatening contingent events they face declines and as a group their size varies less over a given period of time. As a result, they need to be sampled less often in order to arrive at reliable estimates of their abundance. Thus, for older organisms numerical predictions of changes in abundance are more practical and the likelihood of surprise is less. For this reason, fisheries management science has tended to rely almost exclusively on yield-per-recruit models that attempt to predict only the short-term outcomes related to the size or biomass of age cohorts of large fish already (or almost) at maturity (Beverton 1998). The longer time-step of these older fish gives managers (and fishers) the ability to adapt and plan, at least over the span of time each cohort remains alive.

4. Scale and the cost of monitoring

In principle one might argue that any event at any scale in an ecological system is the result of forces that are deterministic; therefore, one ought to be able to monitor at a fine scale, learn the causal relations and eventually predict biological outcomes throughout the system at all scales. If we did have this capability, the problem of collective action would be close to trivial. As neoclassical economics emphasizes, when people are possessed of perfect knowledge almost any assignment of individual resource rights will align individual and social interest in a Pareto-optimal solution, so long as those rights holders are able to engage in costless trades. As a practical matter, however, the costs of acquiring knowledge of even a moderately complex system are substantial. The uncertainties that arise because of these costs impair self-organizing market solutions to our collective problems. It is important, in this regard, that the costs of information about both human and ecological systems tend to be a regular function of scale. For the purposes of fisheries management, for example, we cannot hope to monitor at a very fine scale, certainly not to the point where we can predict the life or death of an individual fish, even though that might be a deterministic event subject to all the laws of nature and, in principle, subject to causative prediction. The frequency and sheer numbers of events at this scale means the costs of careful quantitative monitoring simply overwhelm any conceivable benefit. At a level of aggregation that is somewhat larger, the slower time-step of the natural system means we might be better able to afford to sample, say, a year class of a particular stock. It is not necessary to sample as frequently and the numbers of relevant events are much less. Consequently, we are more able to keep pace with the changes in the abundance of the year class and because of that we are in a better position to extrapolate its abundance into the near future. At still larger scales of communities and ecosystems, the system moves at a longer (slower) time-step. In these circumstances, we are better able to afford matching the frequency of our measurements with the time-step of the system. Unfortunately at these very broad scales the system moves so slowly it is not easy to acquire the experience or frequency of observations necessary to learn its dynamics.

Consequently, if we were to sketch out the relationship between the costs of monitoring and ecological time-step/scale we would trace out a roughly U-shaped curve. Generally the fast rate and extensive detail of fine scale ecological events (and the individual human activities that occur at this same scale) tend to limit our practical ability to monitor quantitatively at very fine temporal and ecological scales. For example, we may never be able to generate reliable quantitative knowledge about the ecological outcomes from either a single or a series of discrete fine scale acts, such as the destruction of habitat or the loss of a population component, but we can acquire and use qualitative knowledge about the impact of these kinds of activities. A second quantitative limit occurs at a broad temporal and ecological scale, in this case because the slow pace of the system limits the frequency of our sampling. Unlike finer scale phenomenon, the costs are principally the costs of waiting. Consequently, the problem we face at both scales is not scientific, per se; instead the problem is that collectively we cannot afford (literally) to rely upon unambiguous quantitative scientific findings to guide collective action at these scales. Consequently, so long as our institutional and administrative structure insists on rigorous scientific evidence, we effectively ignore important ecological phenomenon at both very fine and very broad scales. Needless to say, this impairs our ability to adapt our collective actions to the natural environment.

In the U.S. and probably most other developed countries, this generally means the creation of new institutions, especially fine scales that are able to use qualitative knowledge without simultaneously losing accountability, transparency, and the ability to learn. This is not an argument against the importance of quantitative knowledge; it is simply a statement that there are aspects of natural systems that are important for sustainability for which we cannot economically acquire rigorous scientific knowledge. In those instances – for those parts of the ecosystem – we have to move to institutional arrangements in which personal relationships are able to develop the trust and assurances that we normally and almost uniformly expect to be generated by impersonal, quantitative methods.

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