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Chaos in Fisheries Management

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What's the Problem?

In the current process of coping with the crisis in marine fishery resources, the United States has developed a management technique centered around the creation of eight regional fishery management councils whose primary function is to produce plans for both protecting and enhancing utilization of marine resources.[1] A portion of council positions is filled by individuals whose membership is mandated (e.g., the director of fisheries for each constituent state); other members are selected for fixed terms on the basis of their expertise or working knowledge. Despite regional variation, however,[2] members of the councils are predominantly drawn from, on the one hand, public sector personnel (e.g., administrators, scientists, technicians) and, on the other hand, the user groups - particularly members of the commercial fishing industry.[3]

The currently dominant model of public policy theory is that such diverse groups bring to the negotiating table a diverse range of goals combined with special knowledge and practical expertise, the result of which will be consensual management programs with which "most people can live most of the time." In the case of fisheries management, the process is expected to be capable of producing plans that balance long term conservation of the stocks with optimal economic utilization of the resources.

The context within which the councils operate requires members to recognize political, economic, sociocultural, and biological forces in play. In brief, during the past three decades, the market forces of consumer popularity, technology, and an expansion in the human predator population have combined to increase inroads on the stocks - which, in turn, has led not just to lower landings but, more critically from the biologists' perspective, annual catch statistics indicating an ominous emphasis on single (and younger) year classes. The difficulties of both management and stock maintenance per se are compounded by such additional factors as: (1) the expansion in the number of targeted species which results in increasing pressure on the entire food chain and also increases natural predation opportunities for some species and removes food resources for others; (2) the increase in pollution that may be affecting the reproductive cycle; (3) the alteration, even disappearance of marshes, beaches, and other locales necessary for the reproductive cycle of some species - and thus for all in the chain - forcing the species dependent on them to move elsewhere or die; (4) the targeting of new species about which we know little or nothing, whether of their particular life cycle or their place in the food chain; (5) volatile market forces; (6) a rapidly

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changing commercial fisheries technology (and rising capitalization costs); (7) overlapping demands among multiple users; (8) competing life styles,[4] with special attention to the concerns of those in fishing communities who see both their livelihood and their way of life under attack from all directions.

Hopes for this type of management process were high at the outset since, despite all the complexities, uncertainties, and differences of opinion as to the present and future state of affairs, whether for practical or ideational reasons, all the participants in the management process are agreed on one thing: Steps must be taken to maintain the resources at a viable enough level to sustain the food species for future generations.

As noted, however, this approach involves a delicate juggling of competing economic and political interests, conservation and predation, the public and private good. Thus, the history and results of the process since regional council management was initiated in March 1977, have satisfied few. Charges of overmanagement compete with counterclaims of inadequate regulation – while concern over the present and future condition of the stocks grows; claims that we have too little data for an adequate analysis conflict with arguments that we are buried under data and attention needs to be turned to the production of more robust analytical models in order to gain better understanding of what the data are indicating.

Though a more fine-grained analysis might indicate more categorical subtleties, a first approximation suggests there is one major difficulty that, while hinted at for a number of years, has yet to be spelled out and addressed: *Despite that all accept that, in one form or another, a crisis confronts them, the negotiating participants – in all sectors and at all levels of the management process – are divided by their differing views of Nature.* These views are axiomatic but significantly inform each participant's approach to (1) what constitutes critical or relevant data; (2) how to interpret those data; (3) how to design crisis-appropriate responses. They are variously acquired and systematically integrated as one moves through life, making a series of commitments to various modes of thinking about the world in order to devise decision-making strategies consonant with (or at least are not in opposition to) those held by the primary groups with whom one lives and works.

Consensual Management

It seems clear that at least one of the problems in consensual fisheries management is the basic difference between the ways that representatives of the two groups identified in the opening paragraph view the nature of Nature. The consequences of this difference are twofold; (1) Different information is gathered and interpreted differently; (2) there are sharply divergent perceptions of how to manage – how to make decisions *now* that will produce intended results rather than unintended consequences. Among the longer-term effects are what each group increasingly sees as "the other side's" lack of good faith, good will, and ability to come to grips with the basic characteristics of the need of the fisheries and the industry.

Critical as a variety of factors may be in producing the "noise,"[5] that acts as a barrier among those working to manage the fisheries, a more fundamental barrier to fishery plan production/implementation seems to be a crystallization of two groups, each implicitly holding differing premises about the nature of nature and, given that nature, how to study it, analyze it, and, most importantly, manage it.

Given the basic and fundamental difference between the bargaining of participants in the chain that goes all the way from local public hearings and council activities by the people on "the Hill" in Congress, Commerce, and Cabinet, what has been the result of all this debating, arguing, and horsetrading among these diversely-constituted groups who have been charged to "Do Something"? What has been the product of the labor of all these individuals who know that they must be prepared to negotiate trade-offs, make accommodations, and be open to new input (but not so open-minded they're called "airheads" or, worse, "sell-outs to the other side")? The majority opinion of participants from all sectors is that each plan, once actually implemented, has been insufficient, inappropriate, probably incorrect, and certainly out of date.

What is critical is that each participant in the negotiation and implementation phases of management planning is embedded in a sociocultural matrix from which the primary cognitive mode – a way of perceiving and thinking about the world – is derived. Membership in and an effective affiliation with the group is maintained by articulating its axioms or certain basic, usually unquestioned truths. These are the basic formulas that, if challenged, bring frowns or pitying smirks and charges that the speaker must be "dumb," "asleep at the wheel," or "just plain nuts." Axioms are taken for granted as "right," "rational," and, "it goes without saying." Those who assume that others who, like themselves, possess an expertise in fisheries also assume that these others hold a set of assumptions in common. These are taken as "understood" by all who are "truly knowledgeable" "possessed of common sense."

The Glitch in the System

The catch is that fisheries management in the modern world requires the involvement of a range of civil servants, scientists, and user groups participating in some or all stages of management plan production and implementation. What are the consequences of engaging people with widely differing views of Nature in a project to manage Nature by consensus – especially when one of the engaged groups also has the primary responsibility for acting according to the rules in the day-to-day activities of making a living?

These models provide the yardsticks individuals and groups use when measuring "good" versus "bad management." Unfortunately, their fundamental difference and the extent to which they are rarely made explicit also create a chasm across which dialogue is difficult, if not impossible. "My position" (whether derived from scientific research or practical experience) is grounded in common sense and will surely generate sound plans; "your position" is too general (or too narrow), complex (or too simple), rigid (or ad hoc), costly (or inadequately funded for proper implementation), ignores the human element (or is too vulnerable to manipulation in the political and economic arenas). If or when management programs finally are implemented, such deeply held but rarely explicit stated world views – call them, if you will, cognitive modes – are liable to lead members of, especially, the targeted user group(s) enthusiastically to endorse, comply reluctantly, or rigorously resist the rules and regulations.

In short, the extent to which a group whose members hold diverse viewpoints can produce a *workable* management plan that does not violate their respective axiomatic models (but need not fully reflect them), determines the degree to which industry members cooperate in making the plans work. It will, as well, influence the extent to which fishery managers will perceive the need to continue "fine tuning" the plan, a process that frequently results in continued modification, what has been termed "crisis management" (as when, once in place, the history of a plan is marked by a series of emergency actions to deal with "unexpected" overfishing of juveniles or shortfalls in landings) and what user groups see – sometimes correctly – as a bewildering and contradictory flow of rules and regulations. To this extent, management plans will come close to their target, fall short or overshoot in one or another function – or even careen wildly, producing devastating, unintended consequences.

Natural Systems: Linear and Non-linear

It is when working in the realm of second-guessing nature, particularly the fish stocks, that we are able to see this major distinction emerge. There are, on the one hand, those who view Nature in classic Newtonian terms; on the other hand, there are those whose understanding of natural processes is strikingly parallel to the model being suggested by the newly emerging science of Chaos.[6] Adherents of the first position model the world in terms of linear relationships; those of the second, in non-linear interweavings.

The one group, consisting of the majority of biologists, economists, and ecologists – those scientists and technical experts who are the lead members in marine research studies and in the state/federal agencies concerned with fisheries – see nature as (1) a system and (2) a system in which there is periodic order.[7] Essentially, the study of such a system depends on looking at it locally, studying various species, year classes, sub-regions within the marine econiche, the various ports and their landings, etc. It involves defining perimeters and parameters, identifying relevant variables and utilizing differential equations to describe processes that change smoothly over time. In such a system, one must monitor and measure within a context that stays constant from Time Measurement X_1 to Time Measurement X_2, X_3, etc.

Lending itself to the perception of the rightness of such approaches to understanding the workings of Nature is a tendency among fishery managers to speak of the reproductive process of the stocks as if there were neither interactions among overlapping generations, not unique environmental events affecting generations differently. Overlooking such variables can add credence to the presupposition that one can directly identify the relationship between the number of, say, herring or cod at Time X_1 and the number for Time X_2 – i.e., to express stock dynamics as if the Time X_2 population is a simple function of the Time X_1 population.

Perhaps the classic expression of the linear view of population dynamics – i.e., the view that the nature is ordered, balanced and in dynamic equilibrium – was given by J. Maynard Smith (1968), whose position was that populations either remain relatively constant or regularly vary around some presumed equilibrium point. In the case of commercial fisheries, biologists frequently assume that fishing effort accounts for deviations of real populations from this model and, in the last decade especially, have moved to sustain the stocks by attempting to regulate human predation. As James Gleick put it:

> In a real world system an observer would see just the vertical slice corresponding to one parameter at a time. He would see only one kind of behavior – possibly a steady state, possibly a 7 year cycle, possibly apparent randomness. He would have no way of knowing that the same system, with some slight change in some parameter, could display patterns of a completely different kind (1987:73).[8]

In this cognitive mode, macro-level phenomena are "explained" in terms of a reductive or analytic analysis grounded in the perception that whatever is defined as the observable whole is "the natural result of the interaction between the externally related 'parts'" (Madison 1990:91).[9]

Members of the second group – for the most part industry members, made up of fishermen (and their families), buyers, and processors – see Nature as non-random ("Things don't just happen – there's always got to be a reason") but unpredictable ("If I knew everything that was going to make one trip a winner and another a loser, I'd be God"). Natural processes are complicated and dynamic; causal relations and sequential patterns (if they can be charted at all) can stretch over so long a period that they appear aperiodic. Data selected for review will appear random, disordered, non-causal in their linkages, and chaotic.

The view of Nature held by most in the industry encourages them to see their world (the fish stocks, the weather, the market, the fishery management process, whatever) as continually susceptible to disequilibrium rather than in a linear mode where entropic systems are in constant search for equilibrium. This is a perspective beginning to find some support among scientists. There are strong indications that attempts to understand population dynamics (or the weather, economic activity, or most forms of human behavior for that matter) in terms of linear relationships that can be captured on a straight line graph can be counterproductive. In the case of fisheries management, it may not be a feasible model for managing the resource and it has certainly failed to win cooperation from the industry when plans are actually implemented. Yet, those critically responsible for final plan production – in translating the variety of discussions and hearings that are preliminary to plan submission for federal approval and thus also underwrite their final rejection/approval of plans – are, for the most past, linear models.[10] They approach the understanding of natural processes, as well as the human activities and decisions that affect those processes, with the kinds of assumptions that are both preferred by and required of those who occupy positions within what social scientists label "rational bureaucracies" – management structures in which public policy decisions are, ideally, made in an objective and non-personal fashion.

Although a recognition of non-linear processes has only been achieved in the past decade or so, it's a good guess that industry members (especially those on the front lines, the fishermen), have long organized their knowledge of Nature intuitively in terms of non-linear relationships. "Little things can mean a lot" – and make a big difference. The model of Chaos argues, that *the dynamics of systems can unfold in a non-random but unpredictable fashion.* However, they are labelled "unpredictable" only because those studying them do not (indeed, perhaps cannot) take into account an almost infinite number of small initial perturbations. These are elements ignored, dismissed, and excluded in the decision-making involved in identifying relevant current data or model configurations but highly determining in both calculated and real outcomes. We all learned the principle as school children:

> For want of a nail, a shoe was lost; for want of a shoe, a horse was lost; for want of a horse, a rider was lost; for want of a rider, a message was lost; for want of a message, a battle was lost; for want of a battle, a war was lost; for want of a war, a kingdom was – and all for want of a nail.

In the dynamic universe being modelled by students of Chaotic systems, no input our output can be prejudged to be "irrelevant," or "trivial," and little if anything can be set aside in a category labelled "All things being equal." In non-linear systems, not only does "Every little movement have a meaning all its own" but, more importantly, as the "meaning" of that small event or new input moves through successive layers of ever-more extensive networks, its significance snowballs; its potential to alter future events or characteristics of the system intensifies. Thus, small initial conditions can have a major impact "down the line." When fishermen and those in the buying and processing sector make decisions about resource exploitation, decisions that affect the extent to which they act to violate or comply with regulatory regimes, the non-linear models they use to make their individual decisions are based on a view of Nature as complicated and aperiodic. That view is that each trip, each season, each year's stock almost but never quite repeats itself – in short, that the industry operates in a universe marked by what scientists from a variety of disciplines are now identifying as "Chaotic systems."

Since it is scientists who are identifying this new model, it is clear that the distinction between those arguing for the existence of linear and non-linear views of nature is not a difference between scientists and entrepreneurs, pure theory and dirty practice, those who are smart and dumb, or altruistic (but only, snarl the fishermen, because *their* incomes aren't affected) and greedy (because, sneer the fish managers, they can't see beyond the immediate trip's payoff). People can switch from one to another. Industry personnel usually think in linear terms when making economic decisions, especially capital investment, and, basically, the Chaos model does not deny the basic order of linear thinking dominant in rational, linear thinking, only the difficulty (perhaps impossibility) of including *all* the significant variables in a predictive model.[11]

Given that the chaos model argues that *any* small initial condition or action by a component of a system can generate consequences that magnify and intensify as one moves up to move inclusive systemic levels, it is impossible to have full rationality of action.[12]

Sensitive dependence on initial conditions can produce startling consequences. One of the early proponents of the Chaos paradigm labelled this characteristic "The butterfly effect." As Edward Lorenz put it in an important and early statement of this approach,[13] "the fluttering of a butterfly's wing in Rio de Janeiro, amplified by atmospheric currents, could cause a tornado in Texas two weeks later." Examples of this abound in the real world. Thus, it has been suggested that the crisis at the Three Mile nuclear plant – which led to the entire U.S. nuclear energy program being indefinitely constrained – resulted from one particular workman, at one point in his work schedule, neglecting one gauge on the instrument panel he was supposed to monitor – a gauge obscured by the overhang of his over-generous belly.

To further complicate the issue, it is often difficult to distinguish between two forms of Chaos. The one results from not including critical but periodic components. The second – that being discussed here – is the result of the fact that in a majority of natural, open systems, new information – strangeness – can be introduced, and thereby create a new order. Perturbed by noise (by real randomness), real systems will permit a new variant to emerge that cannot be made to disappear by future noise. In short, a Chaotic entity can also be one in which locally unpredictable innovation – strangeness – can emerge.

Fisheries as Open, Non-linear Systems

The non-linear model is a relatively new way of looking at natural systems. What are some of the effects of using it to study fishery issues?

The market and consumer behavior is one important generator of oscillations in the system. However, in the case of commercial fisheries, consumer taste and market prices also play a role in the equation. Monkfish, once little utilized and often discarded as trash fish, has become enormously popular, pricey and scarce as a result of Julia Child (riding on the crest of the popularity of gourmet dining for the affluent) pushing it on her nationally syndicated TV cooking shows from Boston. On the other hand, the same media can report pollution, contamination and cases of food poisoning and, of course, when this happens, fishermen stop fishing because processors stop buying – and fish buyers stop buying because retailers stop buying because consumers stop buying. Similarly, the North Sea herring stocks, dangerously low in the late 1930s, made an outstanding recovery during World War II for obvious reasons. Thus, the equation must include fishing effort. When a species is popular on the market, pressure increases, stocks decline. When the market ignores a species, the modelers also ignore it and assume a population in long-term equilibrium, rising sharply when small because there is plenty of food and few predators, settling into growth zero at intermediate values, and crashing downward to near zero when large because it exceeds the carrying capacity of its niche. Theoretically, this is how any fish population would behave if fishing effort were removed. Additionally, if we can include fishing effort and this can be measured relative to growth rate (assuming that, say, in 1989 we have an accurate knowledge of the size of the stock and its growth rate), we should be able to predict the species' population size in 1990.

However, when W.E. Ricker used the logistic difference equation to study fisheries in Australia,[14] the growth rate parameter, X, was non-linear, that is, just as with friction, he discovered that growth rate serves as a messy quantity in the modelling of a stock. This means that growth rate is like, say, friction in a hockey game. As Gleick (1987:24) put it:

> ... without friction a simple linear equation expresses the amount of energy you need to accelerate a puck; with friction, the relationship gets complicated because the amount of energy changes depending on how fast the puck is already moving ... the act of playing the game has a way of changing the rules. You cannot assign a constant importance to friction because its importance depends on speed. Speed in turn depends on friction. The twisted changeability makes non-linearity hard to calculate but also creates rich kinds of behavior that concerns the qualitative rather than the quantitative. It asks: if you don't know the measurements, what can you say about the overall structure.

The market and the cumulative effect of fickle consumer patterns (to mention only two) are such quantities.

The distinction between the two models has a powerful effect on analyses that proceed from one or the other. On the one side, a whole of a system is the sum of its parts; on the other side are synergistic systems and therefore the whole is more than the sum of its parts.

Linear-oriented analysts believe that the significant components of a system can be identified so completely that they can identify the appropriate input and predict the results; this is called "fine tuning the system." Those relying on the non-linear approach argue that we can never identify an entity's full synergistic potential – the entity is "sensitive dependent" on initial conditions, which (at least at present) would be impossible to model in a temporal-susceptible entity. Thus, to this extent, nature is unpredictable.

The question of what happens when a Chaotic entity is disturbed is of critical interest to those who are involved in managing nature. Fishermen, especially, are keenly aware of the extent to which small changes can have major effects; a minor mechanical problem leads to a loss of lives; the vessel that steams in just minutes before you do is the last to sell its catch.[15] Those in the commercial

sector resist management because they believe that those who produce the management plans are insensitive to such realities. As one fishermen once said to me:

> By god, those people ["fishcrats"] are stupid! Year after year they come out here with their charts and graphs and measuring tools and go to the same spot at the same time and try to catch fish so they can compare this year's stock with last year's and 10 years ago and so on. And when you tell them that's dim, that that's not going to tell them anything, they mumble about "replicability" and "sampling procedures," and like that. Jeeesus! Don't they understand that fish *swim*? There may be more or less of them, but you'll never find out by checking in one place year after year. Fishermen know that the fish are out there somewhere. That's what we mean by "going fishing."

At least in part of what the fisherman is saying is that a small change in the local water temperature, a ghost-net, some vessel dumping waste overboard can be the minute disturbance that leads to a change that ripples along the food chain, amplifying in scale as it moves up in scale. Many see management plans as doubly damned – imposing overkill responses to normative abnormalities that, in an exercise of hubris and ignorance, managers attempt to eliminate, while ignoring the extent to which Nature is vulnerable to small natural perturbations with large consequences. Over time, industry personnel, particularly fishermen, have created a perspective of and shaped a philosophy about the natural phenomena that underwrites their livelihood. That the technological leap that has occurred in the 20th century has created a problem rarely if ever encountered before, the ability to overfish and wipe out regional stock in a matter of months, even weeks, has not yet been fully incorporated in that view.

> Every time there's a drop in landings, the fishcrats say, "how do we cut back on the fishing?" There are other reasons why fish landings can go down. And that's not to say that there isn't overfishing right now. But you aren't going to solve all – maybe not even most – of the things that can go wrong in the industry with a management plan. Sometimes Nature has a mind of her own, just like a fish does. And you know, we don't really know enough about how it all fits together. Hell! We don't even understand how just one stock works in and of itself, let alone how that stock fits into the whole picture. And these people aren't just tinkering, you know; they're shovelling sand into the works by the ton!

He went on to tell me that he once knew

> ... a man who changed a whole stretch of shore and the fishing because he drained a little piece of marsh for his son to build a house when he got married. But when you try to talk to these people about how things like that must be going on all the time, all over the place, and what that must mean to the fish and the fishing, they just look at you, throw a bunch of equations at you, and imply that because you don't go fishing according to equations, you can't be expected to understand how things really work. And then they pass another regulation to tell me how to fish – not for the condo builders, not the tourists of the marina people or the developers. And not the fish, or the weather, or the pollution. It's only the fishermen who are making the difference.

A recent example of the chasm between fishery managers and industry personnel was the dispute between, on the one hand, a group of commercial fishermen and buyers and, on the other, Dr. William W. Fox, head of the National Marine Fisheries Service, the federal agency most directly responsible for managing U.S. fisheries. The industry personnel filed a civil suit in the U.S. District Court against Fox[16] because a drift gillnet ban

> was imposed ... without benefit of new data or information ... and even though ... a substantial part of the commercial quota for Altantic king mackerel is likely to go unharvested. It was, in the final analysis, imposed on the basis of politics and preconceived conclusions...[17]

As reported in the *National Fisherman* a major news media for the U.S. fishery sector:

> Fox argues that poor information leads to honest differences of opinion. [He states that] "... it depends upon what you do with uncertain data. You can say, 'Well, this doesn't prove there is a problem even though it may imply it. Therefore we aren't going to take any action until we can prove it.' My view is ... to react in a conservative manner in the face of uncertainty" (Fee 1990:15).

Though there are other considerations at work, it is obvious that, for Fox (who teaches fisheries management and is currently in leave from his university position), uncertainty mandates linear modelling as a risk-minimization strategy when faced with uncertainty.

Conclusion

In the final analysis, every management scheme is measured not by its internal consistency and potential for success (*if* all do their part) but by the extent to which people comply with it. And a willingness to comply is usually grounded in a perception that it "makes sense." Industry members will not "follow the rules" if those rules seem too much of the time to violate *their* practical needs and *their* common sense considerations. Fish managers will be forced to "return to the drawing board" continually if their projections prove to be out of kilter with real time events. The consequences? Constant perturbations introduced into a system that, more than most (the managing of, say, forest or water resources), is already marked by unpredictability. Indeed, as those in the industry constantly repeat, it might be better to have a "good enough" (or even a "bad") plan with which there was no constant tinkering, then to aim for the "best" plan. As one New Bedford scalloper said to me (to the accompaniment of approving "Yeahs," "Right on!" and "You said it" from his fellow fishermen): "We could learn to live with *anything* if the damn Feds would just put something in place and then leave it alone for a while."[18]

This discussion has been presented not to argue for the strength or weakness

of one or another model but to demonstrate that both conceptual cores are part of the "intellectual baggage" that each and every participant in every phase of the management process brings to negotiating, planning and implementing fishery plans. This paper argues that different cognitive models *do* exist, *do* play an important role in the way people think about the world, and *do* affect everyday things that everyday people do or choose not to do.

If the existence of these subtle, covert models are sufficient to cause our attempts to deal with the problems to become subverted, perverted, or fall, I think it important to take the time to bring them out into the open, discuss the extent to which they lead to confrontation on issues that are really tangential to the fundamental opposition. It is not easy to question those things that "everyone knows" and that are taken "as given," far from being commonplace, ordinary, and trite, they frequently embody complex, sometimes contradictory components. Even after one starts thinking about them, it can remain difficult to express them lucidly - to oneself and, especially, to others. In a world where attempts to manage are increasing, it is increasingly obvious that how well we can address common problems in non-common contexts really *does* matter. It is critical to address the basic reasons why, as one long-time council member despairingly said to me a few months ago, "Sometimes it seems the more we try, the worse things get."

Notes

1. There is an extended discussion of the structure and processes of these councils in Smith (1982 and 1988).
2. For example, some councils weight the recreational sector more heavily than others.
3. This is especially true for the New England Council, from which the data for this paper were drawn.
4. For example, dwellers in urban ports, recreational coastal communities, retirement villages, or historically embedded rural fishing communities.
5. See, for example, West and Shlesinger (1990).
6. Work going on in this field has strong interconnections with the work being done in mathematics on fractals (scale invariant processes), and with the work going on in a variety of disciplines on spontaneous order or self-ordering critically, catastrophe theory, complex systems, and synergistics.
7. I stress the word "majority" since, obviously, some of those concerned with fisheries management are working with the Chaos model. A recent notable example is the analysis of the Nova Scotia fisheries produced by Allen and McGlade (n.d.). It should also be noted that the categories "linear"/"chaotic thinker" are, in a sense, ideal types; people switch from one model to another in homely ways (e.g., one may think linearly when planning for retirement but non-linearly when trying to understand why one's children behave as they do) and when addressing issues related to professional or scientific thinking (e.g., one may utilize non-linear "hunches" to inform or direct linear cognitive modes).
8. James Gleick's work is a popular, non-technical introduction.
9. For an interesting critique of the economists' utilization of Newtonian thinking, the reader is recommended to Philip Mirowski (1989).
10. This is expectable since the majority have been trained to think in terms of such models and became accredited only after demonstrating their competency in the use of such modes. Barinaga

discusses the extent to which management blunders occur because practitioners are slow to change to more up-to-date procedure – e.g., "The reservoir behind a newly built dam in Idaho is filled for the first time – and the dam collapses due to soil erosion engineers hadn't predicted" or, erring on the other end of the spectrum, "$82 million [was spent] to strengthen Jackson Lake Dam against the possibility of soil liquefaction in an earthquake – even though newer in situ and laboratory tests suggested liquefaction would not be a problem" (1990:356). Barinaga cites lack of communication and fear of legal liability. However, it is likely that, as well, one *could engage* Foucault's arguments concerning the role of the institutionalization and professionalization in creating habitual mind sets from which it is difficult to break free.

11. Speaking within the frame of the model of natural and human systems identified as the product of "spontaneous order," Hayek identifies this mode of sciencing as very different from that predicated on Cartesian rationalism, a rationalism flawed, he argues, since: "Complete rationality of action in the Cartesian sense demands complete knowledge of all relevant facts. A designer or engineer needs all the data and full power to control or manipulate them if he is to organize the material objects to produce the intended result" (1973:12). Indeed, he points out, Cartesian rationalism requires us to believe much "that we cannot know to be true in the Cartesian sense" (ibid.:12). To that extent, then, one might argue that at a certain margin, the commitment to linear models underwritten by extreme rationalism becomes irrational.

12. For one thing, we cannot tell till after the event what input may have been critical (for, obviously, if we had pre-knowledge of its criticality we would have included it). For another thing, even were they known, including all such variables would make for too complicated a model design. Finally, it might not be possible to produce a timely analysis – even with the most powerful computers. It is for this reason that, what in point of fact may be critical variables, are a priori evaluated as "givens" or set to one side in the category of "all things being equal."

13. In a paper presented at the 1979 annual meeting of the American Association for the Advancement of Science.

14. As cited by Gleick (1987:63).

15. Superstitions may be ways of expressing what fishery people understand is the chaotic nature of nature – the extent to which large-scale phenomena are sensitive-dependent on initial conditions. An open hatch is "bad luck;" it's also a condition that can lead to a lost vessel if a sudden storm rises.

16. The judge dismissed the plaintiffs' argument as without merit.

17. Lawsuit filed in Washington D.C. civil action 1990, as reported in Fee (1990:14).

18. It should be noted, however, that (1) industry personnel are just as guilty of calling for changes as the "fishcrats;" (2) one also hears from fishermen that if plans were instituted and left alone, the main reason one could "learn to live with them" is because creative minds would find loopholes and ways around the rules – in short, how to manipulate and cheat the system.

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