Discussion

Notes on Chaos in Fisheries Management by Estellie Smith

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The reader of this commentary may find it useful to know that I am currently working on a social constructivist[1] analysis of the Canadian Department of Fisheries and Oceans (DFO) stock assessment science with particular reference to the role of science in the current perception of a 'crisis' in northern cod stocks.

In the course of my research I have found many of the ideas emerging from chaos theory to be of substantial help in coming to an understanding of why DFO scientists have had difficulty in making assessments and predictions with any useful degree of accuracy, and why it is that DFO (and the institutionalized fisheries management structures of all other industrialized nations that I am aware of) so often fail in their attempts to bring some measure of socio-economic and biological stability to a fishery.

Irrespective of the ultimate acceptance or rejection of the central tenets of chaos theory, it *is* having one undeniably salubrious effect on intellectual activity and academic life. This is its challenge to classical reductionist science and its concomitant tendency to dissolve the barriers that have traditionally separated academic disciplines.[2] In fact, from the perspective of chaos theory, the categorization, compartmentalization and hierarchical ordering of human intellectual activity can be seen as a reflection of the deep structure of the classical scientific paradigm.

In short, I have become deeply impressed with the potential of chaos theory to be a powerful tool in our quest for understanding of the natural world. It appears to have both illuminatory power when directed at problems of complex dynamic systems, such as fisheries, and has entirely welcome tendencies to encourage interdisciplinary research and reintegrate institutionally discrete spheres of human knowledge. That said, I must also acknowledge its current trendiness and, therefore, be unusually critical in my assessments of its incorporation into serious, scholarly work.

The heart of Smith's argument is that the management plans generated through United States regional fisheries councils are generally perceived by all parties as 'failures' because they are the product of a process that attempts to incorporate two fundamentally conflicting 'cognitive models' of natural reality: that of the 'administrators, scientists, [and] technicians ... who view Nature in classic Newtonian terms,' and 'the user groups – primarily members of the commercial fishing industry ... whose understanding of natural processes is strikingly parallel to the model being suggested by the newly emerging science of Chaos' (Smith 1990:1,4).

This hypothesis is intriguing and not without considerable intuitive appeal, but the paucity of supporting data in the article is a serious weakness. Only one secondary source is cited (unconvincingly) in support of Smith's construction of the administra-

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tors' world view: the director of the National Marine Fisheries Service (NMFS), Dr. William W. Fox, is quoted in an article in the *National Fisherman* – a leading industry periodical which has an obvious, 'though unmentioned, stake in the debate. Apropos of a drift gillnet ban imposed by the NFMS the author writes:

> Fox argues that poor information leads to honest differences of opinion. [He states that] '...it depends on what you do with uncertain data. You can say, 'Well, this doesn't prove that there is a problem even though it might 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).

From this Smith concludes that 'it is obvious that, for Fox ... uncertainty mandates linear modelling...' In fact, his remarks are sufficiently ambiguous that they could be interpreted as deriving from either of the two cognitive models under discussion.

Two original sources are quoted as illustrative of fishers' allegedly chaotic cognitive model. The first – unidentified except as 'one fisherman' and offered in no context – is a colloquially eloquent and apparently convincing witness for Smith's case. The second, a 'New Bedford scalloper,' speaks briefly and to no particular purpose.

That said, I must add that I think Smith's hypothesis may well prove to have considerable validity. I suspect, however, that more intensive research will show that the real problem is not so clearly drawn. For instance, I have recently conducted in-depth interviews with more than a dozen Canadian fisheries scientists and managers. Some of them could be loosely characterized as fitting Smith's model while others are, however reluctantly, beginning to suspect that they are dealing with a 'chaotic' system.[3]

Having done no personal research with fishers, I can only say that I expect a similar diversity of cognitive models could be found on this side of the problem as well. I imagine that the skipper of a high-tech deep sea trawler thinks about the marine world in a very different way from the skipper of an open trap skiff. Also, I would suggest that the population dynamics and behavioural characteristics of the target species may be a significant variable in the construction of a fisher's world view.[4]

Contrary to my speculations above, general support for Smith's argument is provided in an editorial in the February, 1991 issue of *Commercial Fisheries News*. Publisher and editor, Robin Alden states:

> Our groundfish debate[5] is crippled by a fundamental difference in perceptions between responsible fishermen and managers ... They [fishermen] perceive both the ecosystem and the market they use as dynamic and unpredictable. They succeed or fail depending on their skill in dealing with uncertainty. Managers, in contrast, have far less at stake and their prescriptions suggest that the ecosystem can be both stable and predictable.

By continuing this line of inquiry (albeit with an expanded data base), Smith, and others, will be making a valuable contribution to our efforts to understand and improve the dynamics and results of fisheries management.

Having dispensed with my discomforting duty as critic I will now offer some more positive commentary and conclude with a brief discussion of chaos theory as it might be applied to fisheries science and management.

In the introductory statement of the problem, Smith identifies several important dynamics at play in the systemic whole. By associating what we have traditionally thought of as 'environmental' processes (biological and oceanographic) with market processes (changes or persistence of consumer demands), technological processes (the ever-increasing 'fishing power' of the harvesting sector), economic processes (the increasing capital cost of harvesting technology), and social processes (conflicting interests of commercial users, recreational users and preservationists),[6] Smith alludes to one of the basic concepts of chaos theory: that the segregation of natural reality into discrete dynamic systems, sub-systems, and successively smaller components, is a product and necessary illusion of reductionist, linear science. In fact, nonlinear dynamic systems may be so sensitive to minor perturbations originating in adjacent or associated systems (the 'butterfly effect' [Lorenz 1979]) that the theoretical boundaries of the concept of 'system' are reached only on the cosmic scale.

If the dynamics of a fisheries ecosystem are predominantly nonlinear, then *all* fisheries management strategies based on linear cause-and-effect models, single-species assessments, predictions and quotas are profoundly flawed and unlikely to achieve their intended results. The essential question then becomes, how *should* we organize and manage our interventions in these systems? The answers will depend on the intended results of fishing and its acceptable and unacceptable known possible effects on the system.

Among the intended results could be, singly or in various combinations and degrees: maximizing the available protein for human consumption, promoting stability and order in the human socio-economic system dependent on fishing, maximizing return on capital or minimizing the fishing-induced perturbations in the system. Among the known possible (extreme) effects it is conceivable that, in a given time and place, it may be acceptable to deliberately fish a stock to commercial or even biological extinction with no regard for the systemic repercussions of such an event. In another time and place it may be entirely unacceptable to risk any such effect.

'But,' you say 'in a nonlinear dynamic system with unknown sensitivity to minor perturbations and unpredictable effects of those perturbations, it is clearly impossible to predict the results or effects of any human intervention in the system no matter how small!' The answer is, well, yes and no. According to chaos theorists and those who are building and testing nonlinear models of fisheries ecosystems, nonlinearity does not necessarily mean unpredictability.[7]

In fact, 'chaos' theory is a deceptive and, perhaps, unfortunate name for this new science. If this body of work can be said to have a central theme, it is that there is a 'strange' kind of order in apparently random or chaotic phenomena. Moreover, this order can be found and is said to be 'self-similar' at all scales of investigation from the cosmic to the sub-atomic. (See note 8 for a short discussion of self-similarity.)

Although the behaviour of natural dynamic systems (the weather, a river, a marine ecosystem) are fundamentally deterministic, the number of determining variables is essentially infinite, and the extreme sensitivity of such systems to initial conditions means that classical linear science is limited in the kind and amount of useful knowledge it can generate about these systems. This is because classical science proceeds on the assumption that the behaviour of natural systems is dominated by a relatively few critical variables. (Ironically, when looking at a system susceptible to the 'butterfly effect,' a classical scientist sees mostly chaos whereas a 'chaotic' scientist sees a 'strange' kind of order. See below)

On the other hand, investigation of dynamic systems with nonlinear analytical tools has revealed that they seem to contain and be dominated by 'strange attractors,' tendencies towards order that exist in 'fractal phase-space.'[8] What this means in practical terms is that, at various knowable (usually fractional) space-time dimensions and energy levels, these systems exhibit dynamic regularity. Realistic models and simulations can be constructed that, in turn, can be used to make useful predictions about the system's future behaviour and likely response to variations in certain parameters. But perhaps the most important aspect of these models is that they can indicate those aspects of the system which we can *never* know – fractal regions of space-time forever obscured from our gaze by an impenetrable, nonlinear chaos. The trick to understanding and coping with nonlinear reality is knowing what questions can be usefully answered and which can not, no matter how much we may wish it. Valid answers and high-probability predictions can only be derived from probing a system in the vicinity of its strange attractors, the fractal space-time dimensions where regularity is found.

Weather forecasting offers a familiar and excellent example. By analyzing available data one may be able to say with a high degree of probability that it will rain heavily this afternoon in Boston but not in New York. (This is because what we call 'humidity, barometric pressure, isotherms, clouds' and so on are also aspects of a nonlinear dynamic system that has been observed to behave with regularity in well-known fractal space-time dimensions.) Between Boston and New York is a huge area of uncertainty where it may or may not rain. Similarly, there is great uncertainty about exactly when the rain will begin and end and exactly how much rain will fall. There are strange attractors in the fractal space-time dimension of 'Boston this afternoon heavy rain' and 'New York this afternoon no rain.' In the fractal dimensions between these strange attractors is chaos. As much as we might wish to know exactly which areas will receive how much rain when, it is, and will forever be, impossible. Still, it is useful to know that it will rain heavily in Boston this afternoon but not in New York.

The fractal space-time dimension of 'Boston rain April' also contains a strange attractor while 'Boston rain April 30' does not. The fractal space-time dimension of 'Boston rain next year' contains a powerful strange attractor while 'Boston rain 200,000 years from now' does not. Notice that strange attractors appear and disappear with changes in scale and that scale is an artifact of the perspective of the observer. The observer is also an interactive part of the dynamic system and, by posing a particular question from a particular point in space-time (and not an infinity of others) and making specific observations (and not others) is actually creating a fractal space-time dimension. It follows that, if the presence or absence of strange attractors is an artifact of observation, then the apparent presence of regularity or chaos must also be a relativistic creation of the act of observation. Further, because the observer cannot create apparent or 'virtual' order or chaos at will, observation must be a dynamic, interactive process existing *within* the system itself; a system containing an infinity of determinant variables massively interactive in an infinity of nonlinear feedback relationships.

An experienced meteorologist chooses to pose questions and make observations – that is, interact within the system in ways – that are known to have a high probability of creating fractal space-time dimensions containing strange attractors.

The point is that we all know and, however grudgingly, accept the relativistic, nonlinear, fractal nature of weather and the limits this places on our knowledge. However, most of us have not yet accepted the relativistic, nonlinear, fractal nature of other dynamic systems such as a marine ecosystem.

What I am rather circuitously arguing is that, to the extent that our fisheries scientists and managers have failed, and will continue to fail, to achieve most of their laudable objectives, it may well be because they are using the wrong conceptual and analytical tools for the job. They are looking for the old, familiar 'A + B = C' linear regularity in space-time dimensions of the system where linear logic would suggest that they find it: relationships between fishing mortality, stock size, spawning biomass, recruitment, predator-prey interactions etc. Occasionally they get lucky and stumble across a strange attractor. More often, though, they are fruitlessly creating and probing fractal dimensions that contain only aperiodic noise: chaos.

They are simply using the wrong tool for the job; rather like trying to eat soup with a fork. It is terribly frustrating, makes a mess and yeilds meager results. There is nothing wrong with classical linear science. It is an admirable, well-developed tool for exploring and exploiting certain orders of phenomena. It has been, and will continue to be, of great benefit to humankind. But until we reconceptualize our approach to fisheries science and management, we will continue to beat our linear heads on a nonlinear brick wall.

Notes

1. From the 'social constructivist' view we see scientific knowledge primarily as a social artifact and a social accomplishment rather than an objective description of external natural reality (Pinch 1986, Mulkay 1979, 1983, Knorr-Cetina 1981, 1983). The most radical treatments portray modern science as the enabling and legitimating belief system of the industrial revolution and the liberal-capitalist State.

2. For example, people with whom I have direct contact who are working on the problems of creating nonlinear, or chaotic, models of fish stock population dynamics include Herb Gaskill, a mathematician at Memorial University of Newfoundland, and Jim Wilson, an economist at the University of Maine at Orono, as well as biologists employed by DFO. These people follow each other's work closely and consider themselves to be colleagues working at the very heart of the same problem; not different, specialized, aspects of a problem. Both Gaskill and Wilson have delved deeply into the body of knowledge traditionally reserved for marine biologists to ensure that the parameters of their models are consistent with current knowledge and the biologists are fluent in the language of mathematics. Further, all of them are aware that social and economic forces have a great deal to do with fisheries management policy and practice and must ultimately be incorporated in any realistic model.

3. In fact, high-energy physicists – traditionally considered to be the 'hardest' scientists of all – have been routinely dealing with uncertainty for quite some time in the form of quantum field theory and quantum mechanics. The two most familiar expressions of the quantum world are Heisenberg's 'Uncertainty Principle' and the famous paradox of 'Schrodinger's Cat.'

4. In her comments on a draft of this paper, Bonnie McCay of Rutgers suggested a radical and potentially productive extension of chaos theory. This is that non-material systems such as public opinion or, in this case, cognitive models, may also be amenable to nonlinear analysis. Specifically, the linear Newtonian model and the nonlinear chaotic model attributed, respectively, by Smith to managers and scientists and to fishers may be thought of as containing 'strange attractors.' In this way we can account for the power and persistence of a belief system irrespective of the real diversity of perception and belief of the system's individual adherents. (See the second half of this paper for a discussion of strange attractors and other aspects of chaos theory.)

5. Regarding proposed measures to achieve a 50 per cent reduction in the fishing mortality rate over the next five years.

6. See the papers of Wilson et al. and Gaskill noted in the appended references for provocative modellings of some of these critical variables.

7. See works by Gleick, Wilson et al., Gaskill and Bak and Chen noted in the appended references.

8. The concept of 'strange attractor' is not too difficult and should become reasonably obvious through its context in the following text. The idea of 'fractal' geometry is considerably tougher. Below I attempt a crude approximation of an explaination.

(However, those interested in furthering their acquaintance with these bizzare but exciting and very useful concepts are strongly recommended to *Chaos: Making a New Science* by James Gleick. This work is universally regarded as the best general introduction to the subject. It also has the great advantage of being splendidly written and a joy to read. A less-heralded but equally interesting text is *Turbulent Mirror* by John Briggs and F. David Peat.)

The classical, Euclidian geometry that we are familiar with is elegantly simple; a point has no dimension, a line one dimension, a plane two dimensions, and space three dimensions. These dimensions can be expressed quantitatively. A point is always '0.' The others are expressed as some variable but absolute quantity respectively called 'length,' 'surface area' and 'volume.'

'Fractal' geometry is the result of Benoit Mandelbrot's disturbing (but retrospectively transparent) observation that it is very difficult, if not impossible, to find these dimensions in the natural world. In *The Fractal Geometry of Nature* (1982) Mandelbrot asked the deceptively simple question, 'What is the length of the British coastline?' His answer was that it varies from zero to infinity depending on the scale of measurement. On a cosmic scale of measurement, light-years, it appears as a point. As the units of measurement are reduced (miles, yards, feet, inches, grains of sand, molecules) the length of the coastline becomes greater until it approaches infinity on the sub-atomic level where it suddenly collapses back into a probabilistic quantum point. Obviously the same is true for the question of the surface area of Britain or the volume of a British lake.

Further, between the cosmic and the atomic scale, at all scales between the macroscopic and microscopic, the shapes and patterns of the British coast were strikingly alike. This, in spite of the fact that these shapes and patterns were the product of undeniably random processes. In many instances it was impossible to determine the scale from the image. Mandelbrot called this phenomenon 'self-similarity.'

Mandelbrot's solution to this problem was to dismiss the idea of absolute quantitative measurement as irrelevant to our investigation of the fundamental properties of nature. What is relevant, he says, is the relative complexity of an object or dynamic process and this can be expressed as a fractional 'fractal' number.

'It's a single model [fractal geometry] that allows us to cope with the range of changing dimensions of the earth. It gives you mathematical and geometric tools to describe and make predictions. Once you get over the hump, and you understand the paradigm, you can actually start measuring things and thinking about things in a new way. You see them differently. You have a new vision. It's not the same as the old vision at all it's much broader' (Scholz in Gleick 1987).

While all of this has no bearing on our mundane activities such as buying rope by a linear measure, cloth by a square measure or concrete by a cubic measure, it is very bad news for many scientists. They are generally trained to take a firmly quantitative approach to natural reality. They prefer precision to messiness. They prefer absolutes to relativity. Even theoretical physicists, who have had a long time to become acquainted with relativity and quantum mechanics, continue to look forward to the day when one of their number will discover the 'theory of everything' that will encapsulate natural reality in one simple mathematical expression.

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