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Feature Article

The Decline in World Wide Oceanic Fishing Harvests: Lotka-Volterra and Related Dynamics

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Open-sea fishing harvests have been declining worldwide since their peak in 1989 (Weber, 1994). The purpose of this project was to determine whether nonlinear dynamics could capture these trends, and whether it was possible to obtain a prediction for the recovery of the main fisheries.

Several lines of reasoning suggest that nonlinear dynamics could be involved, although the implications taken directly from available theory do not point to a consistent picture. The first point of departure is the Lotka-Volterra functions for pre-predator relationships. The system is defined as a closed system consisting of one predator and one prey, e.g., foxes and rabbits. As the rabbit population grows, the food supply for the foxes also increases and does the fox population. Once the collective appetites of the foxes becomes too great for the rabbit population, however, the rabbit population contracts. The fox population contracts shortly thereafter, allowing the rabbit population to increase again. The time series for such a function would be quasi-cyclic showing increases and decreases in the populations of foxes or rabbits. More specifically, the quasi-cycles are thought to be cusp-catastrophic hysteresis functions (Thompson, 1982). On the other hand, continued attempts to analyze actual time series for Canadian lynx shows quasi-cyclicity as expected, but, ultimately, chaotic trends (Stewart, 1989; Tong, 1990).

The open sea fishing situation is not a closed system. Rather the predators, are human-operated, and corporation-owned factory fishing trawlers. These compete with local, less industrialized fishers, and with each other. By current estimates, the world's fishing fleets are already operating at 50% overcapacity relative to the fish that they actually catch (Weber, 1994). Under strictly ecological conditions, these fleets would have contracted substantially, but often continue to operate with the help of financial backing of their governments. Additionally, the human population can leverage itself with other food supplies, and the fleets can switch to new food species, drag the ocean more deeply, and switch to different oceanic basins when the take from one location falls short (Rosser, 1991).

A different principle that could be operating, and often does, is one relating the size of fish to the successive harvest. The function is a simple exponential decay function over time (Brown & Parman, 1993; Kirkpatrick, 1993) such that the biomass available to be caught decreases with each successive harvest because the fish are not allowed to grow to their full and mature size. Eventually, if the target species did not become ecologically extinct, they would become commercially extinct. Repeated harvesting also plays havoc with fish reproductive cycles which are highly variable, as are their mutation rates. Thus current fishing practices are thought to have a strong evolutionary impact on fish (Policansky, 1993).

Although it is common for fisheries managers to consider the case of each species individually, a certain amount of collective or aggregated analysis is required to understand some of the emerging properties of the oceanic ecosystems (Sugihara et al, 1994). For instance, the sharp decline in the Peruvian anchovy was met with a sudden increase in the sardine; the anchovy population did make a sharp recovery eventually. The cod in the Newfoundland fishery, however, might not have a high chance of return as the ecosystem vacated by the cod has been filled by migrations of dogfish (Weber, 1994).

Method

The analytic approach of the present study was, therefore, focussed on the harvested biomass of the 16 major oceanic basins without regard to the specific species involved. Data were the peak catch levels of each basin (expressed in millions of tons), the catch level for 1992, and the number of years that elapsed between the peak and 1992. Data were reported in Weber (1994). (Note: although the world peak was 1989, the separate basins varied in their peak catch years.)

The data were analyzed using the method of hierarchical structural nonlinear regression equations (Guastello, 1995). Because there unequal time intervals in the original data, the variants with time as a variable were used. There were three models were tested. The first was the 1simple chaotic process:

$$(1)\ z_2 = e^{(\theta_1 z_1 t)} + \theta_2,$$

where z was the harvest level corrected for location and scale. The second model tested for the presence of a bifurcation effect where the bifurcation variable itself was not known:

$$(2)\ z_2 = \theta_1\ z_1 e^{(\theta_2 z_1 t)} + \theta_3.$$

The third model tested for time itself as a bifurcation variable:

$$(3)\ z_2 = \theta_1 z_1 t\ e^{(\theta_2 z_1)} + \theta_3.$$

A comparison linear test was automatically built into these analyses with the test on the expon-ential regression weights.

Results

Parameter estimate, R^2 coefficients and dimensionality calculations are shown in Table 1. Lyapunov dimensionality (D_L) is calculated as e^{q1} in Equation 1. In Equations 2 and 3, D_L is $e^{q2} + 1$. All regression weights, except q_2 for Equation 2 were significant.

Table 1
Regression Estimates, R^2 and Lyapunov Dimensionality for Oceanic Fishing Models

Eq.	θ_1	θ_2	θ_3	R^2	D_L
1	0.033	-0.532	NA	.27	1.04
2	0.924	-0.003	0.00	.99	1.00
3.	0.011	0.734	0.370	.80	3.08

Because of its low degree of fit, Equation 1, the simple chaotic model, was ruled out as an explanation of the data. Equation 2 showed that there was a simple linear decline in fishing harvests from the peak to 1992. Because its regression weight in the exponent was zero, its dimensionality was 1.00. It had the highest degree of fit of the three models tested. Figure 2 shows an iteration plot of Equation 2 for different initial conditions. The outcome was beguilingly linear; each successive annual catch is expected to be only 92% of the catch for the previous year. Eventually an asymptotic minimum would be reached.

Equation 3 also showed a high degree of fit, although it was not the best of the three. It was interpreted nonetheless because it illustrated the competing theoretical premises. The dimen-sionality was close to 3.00, and thus signified a cusp-catastrophic process characteristic of the ideal Lotka-Volterra function. The Lyapunov exponent was also positive, and thus denoted that the stable states of the system were chaotic rather than fixed points. Figure 2 is an iterative plot of the resulting function with various initial conditions. Fishing harvests are projected to crash suddenly by 1995, then remain grim for nearly 36 years. After that a catastrophic recovery is expected.

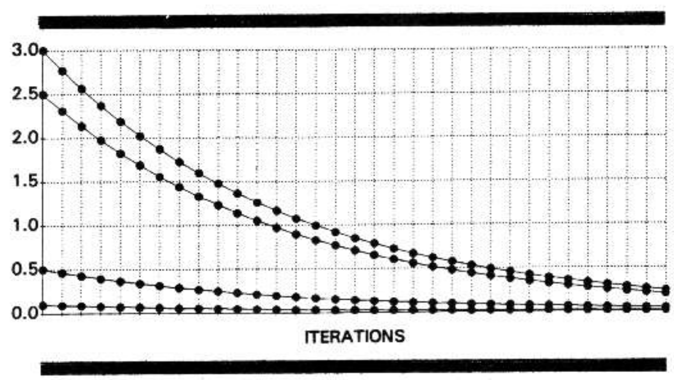

Figure 1. Projections based on Equation 2, model with bifurcation effect unknown and a linear outcome.

Discussion

The results of the analysis showed that it was possible to extract more than one viable and theoretically expected relationship from the data. The model with the better fit illustrated the simple harvest-decay function. It essentially meant that the international fishers would fish the oceans to exhaustion, all things being equal, and the prognosis would be that the exhaustion was permanent. This model tells the story from the point of view of the fishers, what they would capture, and how long the harvests could be maintained.

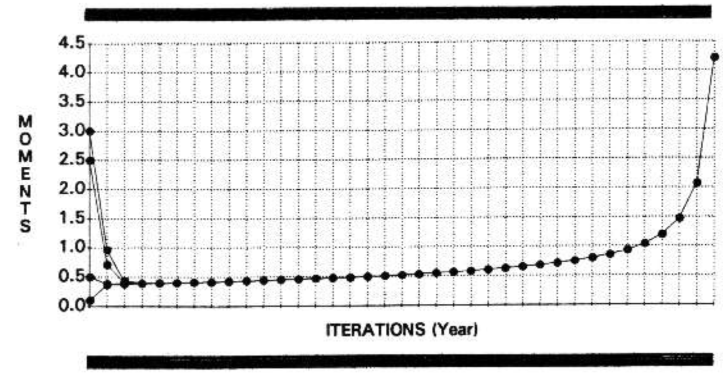

Figure 2. Projections on worldwide fishing harvests based on Equation 3, and showing essentially a Lotka-Volterra function.

The model with time as bifurcation term, however, illustrated both the Lotka-Volterra function at the expected level of dimensionality. It also showed the chaosticity that contemporary researchers also identified through different numerical means and with other data sets. Its projections, however, were from the point of view of the fish; their population dynamics do not anticipate further adaptive responses from the fishers. Rather, if the fish populations were allowed to restore themselves, they would be back in full force. Of course, their populations would not explode as the end of Figure 2 suggests; there would be a limit to the carrying capacities of their environments that was not built into the model.

On the other hand, Figure 2 shows results for total fish quantity. It does not presume that the same species that disappeared will be the ones to recover. For all we know, the recovery would take the form of an abundance of carp and dogfish, rather than orange roughy and cod.

Finally, Figure 2 suggests that the catastrophic decline in harvests should be occurring right about now. Again, adaptive responses by fishers are to dredge deeper than before and to identify new species that were once considered junk. It is probable that these maneuvers would just forestall the inevitable, as depicted in Figure 1.

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