Scripps Scientists Find Potential For Catastrophic Shifts In Pacific Ecosystems

Professor, students document 'nonlinear' mechanisms that could carry large consequences for marine ecosystems

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Opening the door to a new way of understanding ocean processes and managing and protecting marine resources, a group of researchers at Scripps Institution of Oceanography at UCSD, has developed a groundbreaking analysis of the North Pacific Ocean and how dramatic changes can unfold across its waters.

The study, published in the May 19 issue of the journal *Nature*, holds implications for a diverse body of groups, from scientists who study physical ocean processes such as El Niño events to environmental managers charged with overseeing and sustaining ecosystem resources such as fisheries. Surprisingly, it relates to many disciplines involving complex webs of mutually interacting parts, such as ecosystems and world financial markets, which have the potential for unexpected collapse and irreversible change.

Scripps Professor George Sugihara and Scripps students Chih-hao Hsieh, Sarah Glaser and Andrew Lucas conducted the study-an extension of an advanced graduate course at Scripps-that analyzed the underlying dynamics responsible for major shifts in biological and physical conditions of the North Pacific Ocean over the 20th century.

Scientists hoping to understand the behavior of the North Pacific have centered their analyses on "regime shifts," decades-long changes in which semi-stationary periods are followed by periods of rapid transition. Regimes and rapid shifts between regimes are features that arise from so-called "nonlinear" interactions (where mutual effects do more than add-up, they gang-up and multiply). Nonlinear systems have the capacity for behaviors such as chaos and unpredictable changes of state, changes that can be both dramatic and swift.

The researchers discovered that the data for the North Pacific's biological systems exhibited shift-like fluctuations consistent with "nonlinear" mechanisms. Measuring regimes as distinct from random wiggles in oceanographic time series has been elusive until this study. The biological shifts are more than random wiggles.

On the contrary, and to their surprise, the researchers found that some key physical characteristics of the North Pacific, such as sea surface temperature (which were suspected to show regimes), are not nonlinear. Rather, these physical characteristics evolve in a complicated but apparently linear manner, involving the sum of many variables. This finding means that suspected regime-like fluctuations in the North Pacific physical system are for all practical purposes wiggles that are best modeled by traditional statistical approaches. "The dynamics are the same during warm and cold periods, thus they are not true regimes," said Sugihara of the Physical Oceanography Research Division at Scripps. This is at least true for these data from the 20th century.

"Finding nonlinearity is fundamental for understanding and managing changes in ecosystems," said Lucas of the Biological Oceanography Curricular Group at Scripps. "In the North Pacific ecosystem, nonlinearity means that different sets of biological growth rules will apply in each different physical environment and that small, random physical changes can provoke an amplified response in the biology in ways that may not be easily or symmetrically reversed. These measurements show that asymmetrical and even irreversible ecological change is possible."

Irreversibility means that if the ecosystem changes dramatically due to, for example, an increase in temperature from global warming, it will not recover its previous condition simply through an equal but opposite change in temperature. That is, much like a financial market that takes much longer to recover than to crash, an ecosystem that is perturbed into an irreversible shift (e.g., by overfishing) may never be the same afterwards.

Finding linear dynamics in the physics and nonlinear dynamics in the biology in part reconciles an ongoing debate between some physical and biological oceanographers on the nature of long-term change in the North Pacific Ocean.

"Classical fisheries management theory using fixed production functions (fixed growth rules) and fixed harvest targets is no longer supportable," says Sugihara. "The beguilingly simple statement that different sets of growth rules will apply in different physical environments, combined with a randomly fluctuating environment, gives support to a current trend in fisheries toward adaptive management strategies. Fisheries harvest targets need to be flexible and precautionary. This result strengthens the scientific basis for these polices."

The new study is believed to be the first direct test for nonlinearity in large-scale physical and biological data for the marine environment. The basic methods for testing for linear and nonlinear signatures were developed by Sugihara over years of studying a variety of complex systems (ecosystems, atmospheric systems, neurobiological systems, cardiac rhythms, market systems) and their dynamics and have been proven in small-scale ecological applications, medical applications, meteorological applications and in financial applications by investment banks.

"We have shown by analyzing this data with these methods that there is a limit as to what our understanding of the physical and biological interactions is going to be," say the researchers. "It appears we will never be able to explain these processes in a clean and simple way."

Still, there is room for optimism. The authors believe that "with luck and work we may be able to make modestly accurate statistical forecasts over short time horizons as shown with certain reef fish (Science 1999)." The paper by the Scripps team helps to clarify the scientific basis of the next decade's challenge for fisheries and ecosystem management.

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