Ecology

Water temperature and fleas correlated in Lake Windermere

from John H. Steele

WE ARE becoming much more conscious of, and interested in, changes in climate — both the long-term trends and the shorter fluctuations. Although the most direct evidence derives from records of temperature, wind or rainfall, it is often necessary to use biological indicators, such as tree rings or changes in composition of aquatic communities. But that raises questions of the relation between physical and biological variability, witness the arguments about whether 'punctuated equilibrium' is internally driven by ecological or evolutionary processes or is caused by external or even extraterrestrial physical events. Thus direct evidence of relations between climate change and biological patterns, such as the correlation reported on page 536 of this issue between the water temperature in June of Lake Windermere, in northern England, and the abundance of the dominant zooplankton, *Daphnia hyalina*, is always welcome.

Both the temperature and plankton data presented by D.P. George and G.R. Harris show a ten-year cycle over the period 1940–80. There are two other interesting factors noted in the paper. First, the population of the dominant fish, the perch, does not have a similar pattern, indicating to the authors that the fish neither influence nor are influenced by plankton density, at least on these time scales. Second, the ten-year cycle is similar to that observed in the northeast Atlantic, implying a large-scale relevance to the lake's physical and biological data.

Variability in biological data can be related to internal features of the ecological system as well as to external forcing. There has been a longstanding interest in using simple ecological models to investigate cyclical behaviour in populations but there is little acceptable evidence of how this actually happens without changes in the populations' environment. There are still arguments about the explanation of the lynx-hare cycles in the Arctic and the fairly regular outbursts of the spruce budworm. Cyclical behaviour in a particular time series of data may also disappear or be less obvious when more data become available. Thus an ecological system may appear to 'resonate' with its environmental forcing before lapsing back into irregular variations. A ten-year cycle in a forty-year data set raises questions that may be answered only by more observations or by specific causal explanation.

Equally intriguing is the authors' comparison of the temperature cycle in Windermere with that in the eastern North Atlantic, so that the lake data "reflect a

much wider pattern of climatic variation" with a period of approximately ten years. Though one's first thought may be of a possible relation to sun-spot cycles, air temperature records for central England over the past 300 years do not show this periodicity (Shapiro, R. Q. *J.R. met. Soc.* **101**, 697; 1975). Furthermore, a record of sea temperatures off Plymouth over ninety years shows quasi-cyclical changes that go in and out of phase with the sun-spot cycle (Southward, A.J. *Nature* **285**, 361; 1980).

If the correspondence in lake and sea temperatures is not mediated directly by air temperature, what other factors might be involved? In an analysis of the changes between 1873 and 1972 of the intensity of westerly winds over the North Atlantic, T.J. Makrogiannis *et al.* (*J. Clim.* **2**, 159; 1982) found, although they could not

easily explain, a ten-year periodicity. As George and Harris suggest, the link between temperatures in Windermere and the open ocean may arise indirectly through comparable variations in wind-induced mixing in the two very different aquatic systems. Again, there are questions about which processes in the ocean and atmosphere could generate such long-period cycles. Is there a northern oscillation like the southern oscillation associated with El Niño? It must be noted that all the longer-term data sets have several spectral peaks at frequencies from months to a few decades. Thus the interactions between oceans, atmosphere and lakes occur over a wide temporal range and will affect the biology in different ways.

These correlations between physical and biological events and between the open ocean and a mountain lake are tantalizing. Raising more questions than they answer, they demonstrate the need not only for longer data sets in aquatic environments but especially for studies of the causal interactions between land, ocean and atmosphere. □

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Cosmology

How did the Universe begin?

from I.G. Moss

BY AND large, cosmologists have become accustomed to the idea that the Universe began with an initial singularity of infinite density and infinitesimally small volume. This idea is strongly supported by the singularity theorems which Penrose and Hawking produced in the 1960s. But now, in an about-face that has come from a consideration of quantum mechanical effects on the origin of the Universe, Hawking and colleagues suggest that the Universe had a non-singular beginning followed by a period of very rapid expansion (which goes under the name of inflation¹) and then a transition to the conventional development described by the hot big-bang model. A longstanding problem of cosmology, to explain the origin of the density fluctuations that are needed to account for galaxies, is solved along the way by quantum fluctuations².

The problems of combining quantum mechanics with Einstein's theory of gravity still remain to be solved, but there does exist a coordinate-independent formalism of quantum mechanics (that is, one consistent with general covariance) invented by John Wheeler³ and Bryce DeWitt⁴. This very beautiful theory deserves to be better known. The wave function is a function of the geometry of space and of the matter fields. As a consequence of general covariance, the wave function satisfies a wave equation, known as the Wheeler–DeWitt

equation, which turns out to be the gravitational analogue of Schrödinger's equation. Thus, choosing the boundary conditions for this differential equation is analogous to choosing the initial conditions in a classical treatment of cosmology.

It was hoped that there would be only one solution of the Wheeler–DeWitt equation consistent with reasonable regularity conditions on the wave function but, as yet, there is no evidence that this is the case. Instead, Stephen Hawking has formulated a principle of quantum cosmology which produces one solution with particularly nice properties⁵. This wave function is constructed from the sum of many amplitudes for space-times with finite volume but no boundary. Hawking describes this by the cryptic statement⁶: "The boundary condition of the universe is that it has no boundary". His wave function is non-singular at space-time singularities and also has the property that it puts the matter fields into their ground state initially.

The first calculations of the wave function for the inflationary universe using Hawking's principle^{7,8} were performed on a model of the universe in which only a very small number of degrees of freedom are included (mini-superspace). These wave functions show recognizable features that correspond to the inflationary era and the matter-dominated era of