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VIEWPOINT

Investigating Long-Term Ecological Variability Using the Global Population Dynamics Database

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The Global Population Dynamics Database (GPDD) is an important new source of information for ecologists, resource managers, and environmental scientists interested in the dynamics of natural populations. It comprises more than 4500 time series of population abundance for over 1800 animal species across many taxonomic groups and geographical locations. The GPDD offers great potential for asking comparative questions about the nature of population variability. We illustrate this by characterizing some critical features of ecological variability, variance growth, and spectral reddening.

The gathering of population time series is a lengthy process, and many ecologists have committed themselves to a lifetime of work to accumulate detailed information on populations at certain sites over many years. This information has often been difficult for these people to publicize and for others to obtain. This in turn has hampered the formulation and testing of general ecological theories and the investigation of large-scale spatial and temporal patterns. The goal of the Global

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Population Dynamics Database (GPDD) has been to use the potential of the global Internet to address this challenge and make available to ecologists an extensive database of ecological time series. The GPDD (*1*) (Fig. 1) was built by the NERC Centre for Population Biology (Imperial College, Silwood Park, United Kingdom) in collaboration with the National Center for Ecological Analysis and Synthesis (University of California, Santa Barbara), and the Department of Ecology and Evolution, University of Tennessee. Comprising more than 4500 time series of population abundance longer than 10 years for over 1800 animal species across many geographical locations, it is the largest collection of an-

imal population data available to ecologists. The GPDD is constantly updated with new information from the published literature and from previously unpublished data, and its freely searchable structure offers a wealth of opportunities for comparative analyses of population dynamics. We illustrate this potential [see also (*2*)] by investigating the so-called "more time, more variation" effect (*3*, *4*) in animal populations using the GPDD.

Preliminary studies have shown that the magnitude of temporal variability depends on a species' body size, its reproductive rate, and the features of the food web structure in which the species is embedded (*5*). However, there is also a prevailing tendency, across a wide variety of species, for temporal variability to increase with the length of the census (*3*, *5–9*). This "more time, more variation" effect has already inspired considerable discussion, both as to its possible origin (*3*, *4*, *10–12*) and implications (*3–7*, *10*). It has usually been associated with "spectral reddening" (a tendency for low or high abundances to be followed by more of the same) of population

dynamics. Dynamics can become reddened in several ways: Redness can be inherited from variation in the environment (12), it may arise through certain types of stochastic density dependence (7), or it may be generated through long-range spatial interactions (11). The effects of increasing variability are important and are subject to debate. For example, one would expect a population whose numbers fluctuate more over time to have a greater risk of extinction (3–5), although this need not always be so (13).

In using the resources of the GPDD, we were interested in the magnitude of the growth of population variability and how this differed across taxa and trophic level (both of these ecological covariates are available with the GPDD). We were also interested to see whether the more time, more variation effect is indeed associated with spectral reddening (3–5, 10). For the analysis, we used all annual series longer than 30 years. The GPDD contains 544 such series, representing 123 species with a

median length of 46.5 years (the longest series is 157 years). Our results (14) confirm and extend the findings of previous authors (3, 6–10) that population variability increases with time series length. Both the variability of animal populations over 30 years and its rate of increase tend to be remarkably similar across different taxa and trophic levels (although for insects the former tends to be higher). In most cases (96.9%), the increase in population variability decelerates with time series length (Fig. 2A). However, this deceleration need not imply convergence to an upper limit (7, 13), and for the majority of ecological series, variance fails to exhibit an overall tendency to converge to any limit, at least over ecologically observable time scales. The increase in population variability is strongly associated with spectral reddening (Fig. 2B). For most of the time series (92%), the spectral redness exponent (10, 14) was in a range from −2 to 0; that is, between a random walk and time independence. The overall mean value of −1.022 (SE = 0.025, n = 544 time series) is close to the value associated with 1/f or pink noise, a process whose variance grows slowly over time (10, 13). Spectral reddening is not the only way in which population variability may increase with time. An alternative is through the mechanism of "heavy-tailed" probability distributions, with an infinite theoretical variance (15). This has been observed in certain economic and other time series but is unlikely to play a significant role in ecological time series (16).

Traditional models of density-dependent growth imply the existence of a "basin of attraction," which confines the fluctuation of population abundance to a well-defined range of values about equilibrium. Thus, for tightly regulated populations, the variance should

Fig. 1. The GPDD home page (http://cpbnts1.bio.ic.ac.uk/gpdd/), showing the structure of the database.
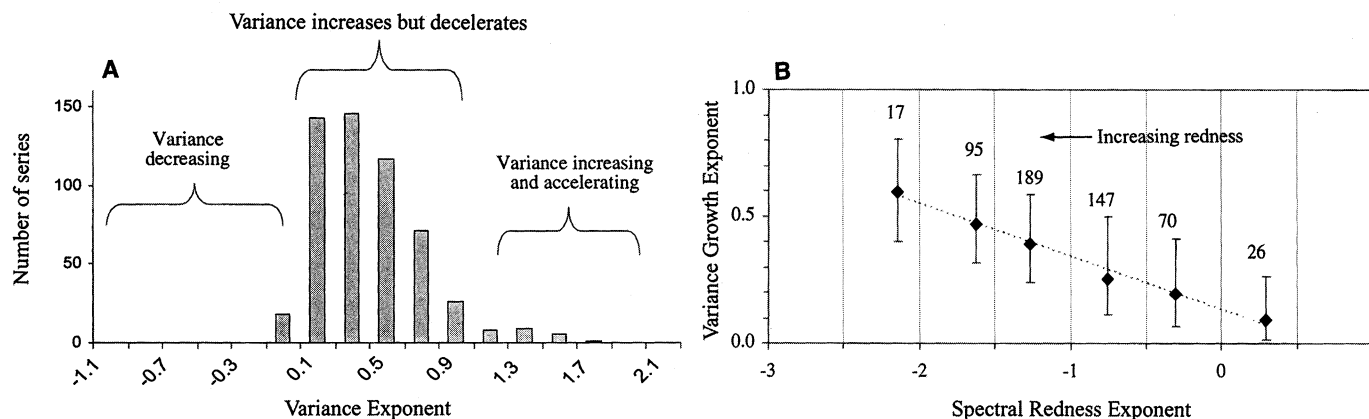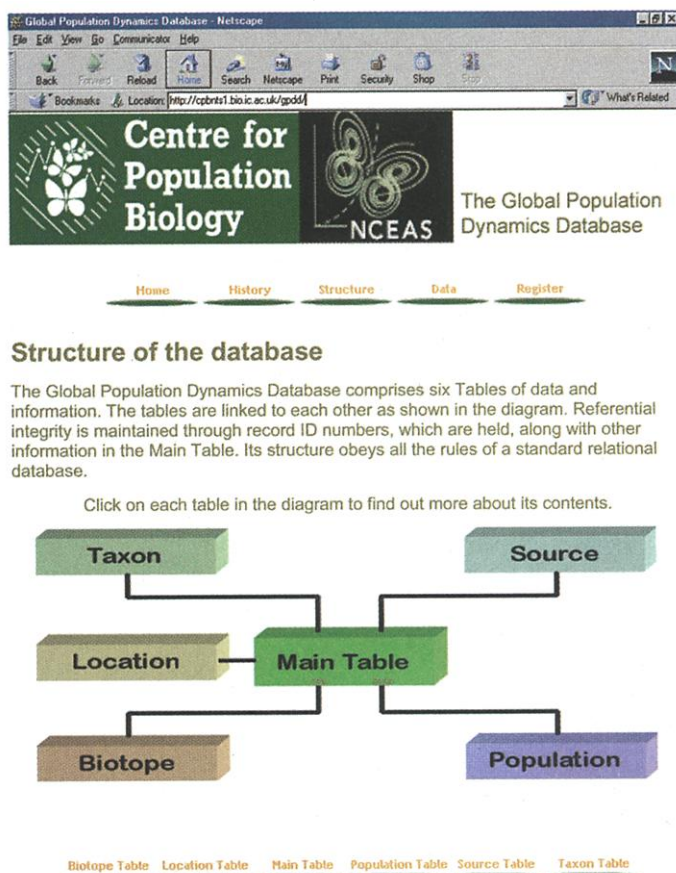

Fig. 2. Frequency distribution of the variance growth exponents for the 544 time series analyzed (A) and the association between variance growth and spectral redness (B). The 544 observations were grouped into classes according to the value of the spectral redness exponent. There were six classes, defined as follows: below −2, −2 to −1.5, −1.5 to −1, −1 to −0.5, −0.5 to 0, and >0. Each ordinate is the median variance growth exponent (error bars represent the first and third quartiles) for all observations in the associated class, whereas the abscissa is defined by the median redness exponent for that class. The numbers in each class are shown above each point.

converge to a clear limit in long enough series (6, 7, 17, 18). Toward the other end of the range of conceivable behavior lies density-independent stochastic growth, the prime example of which is a random walk, for which the variance grows linearly with time (7, 13). It seems (Fig. 2A) that the dynamics of animal populations, on the longest time scales available to us, lie somewhere between these two poles. These results show that population variability is not a single fixed quantity. The incorporation of some measure of variance increase into widely used measures of temporal variability (such as the coefficient of variation or the standard deviation of the logarithm of abundance) offers the possibility of substantially improving the understanding of ecological variability.

Often, the limiting factor while investigating ecological phenomena and in the development of theory to explain them has been the availability of suitable long-term data. As we have illustrated here, the GPDD now offers an unprecedented opportunity to undertake broad-scale comparative studies aimed at understanding the main features of population dynamics.

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VIEWPOINT

Ecological Forecasts: An Emerging Imperative

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Planning and decision-making can be improved by access to reliable forecasts of ecosystem state, ecosystem services, and natural capital. Availability of new data sets, together with progress in computation and statistics, will increase our ability to forecast ecosystem change. An agenda that would lead toward a capacity to produce, evaluate, and communicate forecasts of critical ecosystem services requires a process that engages scientists and decision-makers. Interdisciplinary linkages are necessary because of the climate and societal controls on ecosystems, the feedbacks involving social change, and the decision-making relevance of forecasts.

Scientists and policy-makers can agree that success in dealing with environmental change rests with a capacity to anticipate. Rapid change in climate and chemical cycles, depletion of the natural resources that support regional economies, proliferation of exotic species, spread of disease, and deterioration of air, waters, and soils pose unprecedented threats to human civilization. Continued food, fiber, and freshwater supplies and the maintenance of human health depend on our ability to anticipate and prepare for the uncertain future (1). Anticipating many of the environmental challenges of coming decades requires improved scientific understanding. An evolving science of ecological forecasting is beginning to emerge and could have an expanding role in policy and management.

An initiative in ecological forecasting must define the appropriate role of science in the decision-making process and the research that is required to develop the capability. Ecological forecasting is defined here as the process of predicting the state of ecosystems,

ecosystem services, and natural capital, with fully specified uncertainties, and is contingent on explicit scenarios for climate, land use, human population, technologies, and economic activity. The spatial extent ranges from small plots to regions to continents to the globe. The time horizon can extend up to 50 years. The information content of a forecast is inversely proportional to forecast uncertainty (2). A wide confidence envelope indicates low information content. A scenario assumes changes in "possible future boundary conditions (e.g., emissions scenarios). . . . For the decision maker, scenarios provide an indication of possibilities, but not definitive probabilities" (3). Scenarios can be the basis for projections, which apply the tools of ecological forecasting to specific scenarios.

What Is Forecastable?

Accurate estimation and communication of information content will determine the success of an ecological forecasting initiative. "Forecastable" ecosystem attributes are ones

for which uncertainty can be reduced to the point where a forecast reports a useful amount of information. Information content is affected by all sources of stochasticity.

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