is "Truth is what you find at the end of a correct chain of arguments."

The author quotes Einstein: "The reason why mathematics enjoys special esteem, above all other sciences, is that its laws are absolutely certain and indisputable, while those of all other sciences are to some extent debatable." Two plus two cannot be anything but four, but when one applies this tautology to the world one has to invoke what the philosopher Rudolph Carnap called "correspondence rules". These are assumptions such as that a pebble, a cow or a star is taken as 1. If such equivalence is not assumed, then $2 + 2 = 4$ is violated by, for example, the fact that two drops of water added to two drops makes one big drop. Nothing could be simpler than this obvious distinction between pure and applied, yet some philosophers and mathematicians, frightened by the word 'truth', seem unable to grasp it.

King shares physicist Eugene Wigner's puzzlement over the "unreasonable effectiveness" of mathematics. This puzzlement puzzles me. Not only is the Universe mathematically structured, it is made entirely of mathematics. Matter consists of fields and their particles, which are not made of anything except equations. What is so mysterious about the application of these equations to a Universe from which our minds, in turn made of mathematics, originally extracted them? If mathematical patterns are not discovered, but are entirely human creations like poetry and music, then their powerful effectiveness in science and technology is indeed what Wigner called an undeserved miracle.

King is particularly fond of the poetry of Robert Frost. His poems "stay with you because of their simplicity: you come back to them for their depth . . . Frost brought poetry to the multitudes; let's now bring them mathematics." The Frosts of mathematics have yet to appear, but King is "certain as sunrise" that they will some day revolutionize mathematical teaching.

The author has a romantic vision of himself as "an aging gunfighter, walking alone the mean streets of academe". His fire is aimed at a conservative elite too self-absorbed in their specialized research to be much concerned about the public's growing mathematical illiteracy. The dull "cinder-block textbooks" get "clunkier". Although their diagrams are splattered with colour, somehow the splendour of ideas behind the diagrams remains as invisible as the textbook authors. Meanwhile the M- and N-cultures "fly apart like galaxies on opposite sides of an expanding universe". □

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Holding tight — the pioneering rocket experimentalist Robert H. Goddard (second from right) displaying a liquid-propulsion rocket used in a flight in 1932. Picture from *History of Liquid Rocket Engine Development in the United States 1955–1980* edited by S. E. Doyle. American Astronautical Society, \$50 (hbk), \$35 (pbk).

Differentiating diseases

Denis Mollison

Infectious Diseases of Humans: Dynamics and Control. By Roy M. Anderson and Robert M. May. Oxford University Press: 1991. Pp. 757. £50, \$95 (hbk); £22.50, \$45 (pbk).

THROUGHOUT history, many more people have been killed by infectious diseases than by wars. One spectacular example is the conquest of the Americas following Columbus's arrival 500 years ago. The sudden collapse of the great Aztec and Inca empires could not have happened without the help of smallpox and other 'European' diseases. Often spreading faster than the colonists themselves, these microscopic invaders in a few years reduced the native population to less than a tenth of what it had been previously.

Despite such evidence of the enormous impact of infectious diseases, it is little more than 100 years since the germ theory of disease won general acceptance through the work of Pasteur, Koch and others. Mathematical modelling of disease began in the early years of this century with, for instance, Hamer and Soper's work on the basic dynamics of outbreaks and recurrent cycles of endemic diseases such as measles. Over the past 30 years or so, the literature of theoretical epidemiology has gathered pace, rather as though it were itself a new and virulent disease.

As Anderson and May point out, much of this work has become too detached from data, as well as from public health policy. Their primary aim in this book is "to show how simple mathematical models of the transmission of infectious agents within human communities

can help to interpret observed epidemiological trends, to guide the collection of data towards further understanding, and to design programmes for the control of infection and disease".

Anderson and May divide infectious diseases into two broad classes, requiring different kinds of models, according to whether the diseases are caused by microparasites or macroparasites, the key distinction being that the former reproduce directly in the human host. For each class, they begin with simple static models for a stable situation of endemic disease and with simple dynamic models, before introducing important complications such as age dependence, genetic, social and spatial heterogeneity, and the problems of control. In each case, the modelling is clearly motivated by real diseases, and the discussion tied closely to clear presentations of data across the range of human infectious diseases.

This structure works beautifully, avoiding repetition and bringing out the similarities between diseases whose behaviours are superficially very different. There is a welcome emphasis on starting with simple models, so as to avoid, in the authors' words, becoming lost in "a snowstorm of parameters". It is still insufficiently recognized in mathematical biology that the 'flexibility' of a model with many parameters often amounts to meaninglessness, in that such a model can be fitted to anything; as an eighteenth-century mathematician once put it: "give me five parameters and I will draw you an elephant, six and I will have him wave his trunk".

The authors' mathematical approach is based on differential equations. Although possibly off-putting in appearance, at least to the biological and medical scientists at whom the book is aimed, these equations are straightforward and well-understood mathematical tools, and allow the authors to consider

a marvellously thorough range of aspects of disease, from comparison of different vaccination policies to the coevolution of host and parasite populations.

Differential equations in biology do have their problems, however. Their air of apparent precision (mimicking the genuine precision of, say, the law of gravity, $\ddot{x} = -gx$) can mislead the unwary. For instance, it is a common and reasonable simplification to represent the rate at which infected individuals recover as being proportional to the number of infected individuals: in its simplest form, $\dot{Y} = -\mu Y$. Unfortunately, this form carries the implicit assumption that the duration of the infectious period has a specific distribution, the exponential, which is a poor approximation in most cases. Although this unwanted precise assumption generally has little effect on the dynamics of the model, it can make a difference to the stability or otherwise of the endemic state.

Sorting out robust conclusions from those that are sensitive to unreliable modelling detail is a delicate task for the mathematician. Regrettably, biologists often use this overprecision as an excuse to dismiss the mathematical approach to disease dynamics (or, equally undesirably, they swallow specific differential equations uncritically). May and Anderson are, of course, well aware of such problems, and are full of insights into the general qualitative truths that lie behind specific details. A nice example is their summary of the timescales of dynamics in terms of those of the disease itself (its 'generation gap', D) and the human population (its mean lifetime, L). They describe the initial epidemic outbreak, the regrowth of susceptibles that follows, and the later coupling of infected and susceptible individuals in endemic oscillations, as being on timescales of D , L and their geometric mean $\sqrt{DL}$, respectively.

Even Anderson and May can get caught up in the obfuscations of the differential-equation approach, as in their basic consideration of equilibrium in chapter 4. Here they establish a number of simple and appealing results, relating basic epidemic and population parameters, as approximations in specific cases, when slight modifications can be shown to hold more generally by simply considering the logically possible flows between disease states.

At a deeper level, many such simple relationships become poor approximations when one gets into the complexities of population heterogeneity. Some of these complexities may require models framed in terms of individuals; a basic imprecision of differential equations is their treatment of population as a continuous mass, which makes it difficult to use them to model spatial or social

contact structures. Corresponding data studies at the individual and local level will also be required. Recent improvements in computer technology have helped here by providing better databases, and by opening up new possibilities for the use of computer-intensive methods in the analysis of data.

This is a masterly survey of a wide range of aspects of the dynamics of human diseases. It is difficult to see how such width could have been achieved other than by using simple differential-

equation models. But these models rarely provide the last word; when one considers the details of populations, it is often unclear what level of accuracy has been achieved. The book should therefore be seen as setting a rich agenda for further research rather than as a final solution. □

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Taming the oceans of the world

Donald S. McLusky

Dynamics of Marine Ecosystems: Biological-Physical Interactions in the Oceans. By K. H. Mann and J. R. N. Lazier. *Blackwell Scientific*: 1991. Pp. 466. £24.95, \$46.95 (pbk).

WHEN A. G. Tansley introduced the term "ecosystem" in 1935, he stressed the interaction between living and non-living components. Over the years, biologists have come to use the word mainly for studies of the energy transfers within food webs. These studies have been useful for coordinating research and as models for explaining ecological principles. At the same time, physical techniques have become more sophisticated and scientists can now study processes in the world's seas using satellite imagery and other ways of collecting data quickly and directly.

Mann and Lazier claim that the time has come to rejoin these two branches of study, with marine ecology emerging as an integrated discipline concerned with the physics, chemistry and biology of the sea. The relevance of this new marine ecology has probably never been greater: the physical processes underlying large-scale biological phenomena such as production at upwellings of fronts are now better understood; measurements of biological and physical parameters can be made at truly comparable levels; the need to understand the influence of marine ecological processes on world climate is urgent; and a study of fundamental ecological processes is important in ocean management.

The book is imaginatively divided into three sections on the basis of scale. The first is concerned with processes on a scale of less than 1 km. The authors admit that grappling with the physics of turbulent flow is hard labour for many biologists but claim that it is essential for understanding contemporary marine ecology. From this beginning, the reader approaches the vertical structure of the ocean. Here the authors acknowledge

that the long-term understanding based on Sverdrup's observations has been confirmed by modern technology. From a combined physical and biological understanding, four general patterns of primary production in the oceans can now be recognized.

In the second section, the authors discuss processes on a scale of 1–1,000 km, and include detailed accounts of coastal upwelling based on studies of the Canary, Peru, California and Benguela currents, and studies of fronts in coastal waters. The authors freely confess that the latter field is new and that there is so far no consensus among researchers.

The third section covers processes on a scale of thousands of kilometres, including the circulation of the ocean basins, and the biological consequences of variability in ocean circulation, including events from the North Sea and the Pacific. In the final chapter, the authors look at the oceans and global climate change. They point out the crucial role of the oceans in carbon dioxide balance — the oceans and their sediments contain almost all the carbon dioxide ever issued into the atmosphere. They also consider the many complications in assessing the role of phytoplankton in pumping carbon into the interior of the oceans and, after summarizing the many alternatives, wisely conclude that it is, as yet, impossible to be certain what the overall effects will be on the oceans or the atmosphere.

The book is well written and the authors' approach works well. They give a clear plan in the first chapter of their aim to unite varied disciplines, and each chapter is complemented by a simple summary, as well as 'boxes' to provide supplementary reading or formulae. I am sure that the book will be adopted as a standard text for many marine science courses. More importantly, it highlights enough unanswered questions to motivate a new generation of researchers. □

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