HOW WE MOVE

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exceed those that can be readily measured in currency. They can also include unemployment, impacts on infrastructure, food and water shortages, environmental degradation, loss of biodiversity, increased rates and severity of natural disasters, illness, and even loss of lives.

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Principles of Animal Locomotion. R. McNeill Alexander. Princeton University Press, Princeton, NJ, 2003. 376 pp., illus. $49.50 (ISBN 0691086788 cloth).

A remarkable conference was held in Edinburgh in March 1999. Its purpose was to pay tribute, in the year of his retirement, to R. McNeill Alexander. The conference was attended by delegates from all over the world who had assembled to honor the man who is regarded as the most influential and knowledgeable person in the related fields of biomechanics, animal design, and animal locomotion. Alexander has been publishing in these fields for more than 40 years; his work has given rise to new understandings of the design and functioning of animals as diverse as fishes, roundworms, and dinosaurs. In every case, his insight has opened the eyes of others to new research opportunities. He has achieved his father-figure status partly by producing a copious and steady stream of research papers but also by covering a broad range of topics in reviews and in more than 10 books, ranging from accessible and influential undergraduate textbooks to specialized research monographs.

Alexander's most recent book, *Principles of Animal Locomotion,* covers all aspects of animal locomotion, from terrestrial walking, crawling, and burrowing to flying (including gliding and powered flight) and swimming by animals of different sizes. The book is supported by over 30 pages of references and by numerous tables and line drawings. The first five chapters introduce the underlying problems and principles that are explored in the central chapters that deal with particular modes of transport. Chapter 1, "The Best Way to Travel," considers problems of selective importance such as whether—and when—it is better to go for outright speed or for acceleration and maneuverability. Chapter 2, "Muscle, the Motor," considers muscles as generators of force, power, and work, as well as their architecture in the body and their energy requirements and efficiencies. This highly informative chapter—a must for any study of locomotion—leads into a chapter on the energy requirements for locomotion, exploring kinetic, potential, and elastic strain energy, frictional and inertial costs, and, in the absence of wheels, the costs of stopping and starting parts of the body.

Next comes an exploration of the consequences of an animal's size: similarity, allometry, and more specialized questions of dynamic and elastic similarity, which have been the subjects of considerable discussion over the past 25 years and in which Alexander has played a major part. This chapter introduces three dimension-less numbers: the Reynolds number, which applies to the flow conditions and forces acting on bodies of different sizes moving at different speeds in different fluids; the Froude number (more properly the second Froude number), which is the ratio between gravitational and inertial forces; and the Strouhal number, which compares oscillatory or repetitive movements at different frequencies in fluids flowing at different speeds over different distances. Interestingly, all these numbers were originally applied in engineering and have been turned into basic tools in the study of animal locomotion.

The introductory section ends with a useful chapter on the techniques used to study locomotion, the scope and limitations of these techniques, and the analysis of data. This chapter highlights the extent to which research on locomotion has required the design of apparatus adapted to the specialized requirements of the work. For example, it is difficult to measure the force exerted by a muscle or how its length changes during locomotion, but Alexander describes methods by which these measurements have been made.

Now we enter the meat of the book: the 13 central chapters on different modes of locomotion. Alexander starts with terrestrial locomotion, which he introduces by laying out the ground rules and problems associated with using legs and bodies in different ways and the associated costs and losses. (He includes one problem amusingly called "an inelastic kangaroo.") This leads into running, walking, and hopping, an area in which Alexander's own research, and particularly his application of the Froude number, has revolutionized our understanding of how animals use their legs. These and the chapters on jumping, climbing, and burrowing show how far our understanding of these modes of transportation has come over the past few years.

The chapters on flying and swimming emphasize how this field has been transformed by recent studies of unsteady-

state fluid dynamics and vorticity. These approaches go back to the beginning of the 20th century but, because they are not so important in airplane and ship design, have only recently been brought to bear on animal locomotion, where they have been able to provide convincing accounts of the ways flapping wings produce lift and fish tails produce thrust. The treatment is exhaustive—but it does make exhausting reading. The penultimate chapter, "Aids to Human Locomotion," is brief and amusing. Here Alexander considers a diversity of tools, from shoes to bicycles and hang gliders. What emerges is that well-engineered shoes or bicycles are worthwhile, but human-powered flight—for practical purposes—is futile.

The book is illustrated with clear line drawings, many of which are original, and liberally sprinkled with equations that range from simple to complex. If, like me, you find Alexander's facility with mathematics and calculus daunting, you will seek, as I did, a "child's guide" to what he explains. To me, this is a weakness of the book—Alexander rarely takes the opportunity to offer simple summaries so that the reader can see where the story is leading or what it has shown. At the end of each chapter, however, he does offer his views on avenues for future research—and very interesting they are. Those who, like me, are familiar with Alexander's style will not be surprised by his approach: "Let the mass of an animal be *m*" or "Consider an animal of mass *m*" is a typical way for him to open or discuss a particular situation. This is effective, though often a little dry. A dry humor does appear—though rarely—in his work, as in his discussion of the complex muscle architecture of fishes: "My theory...has been challenged and may be wrong" (p. 287). And he can be pithily effective, as, when describing the gait changes of a pony, he writes that it "should walk at speeds less than 1.7 m/s [meters per second], trot between that speed and 4.6 m/s and gallop at higher speeds. This is what it did" (p. 128).

This is not easy reading. Do not expect to pick it up just to browse through it. It is in total contrast to Alexander's earlier book, *Locomotion of Animals* (1982), which is now sadly out of date but which can still act as a useful primer for the present book. Despite cover notes announcing that the book will be "enormously useful to advanced undergraduates," do not expect them to find it accessible. It is hard work but worthwhile and authoritative.

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UNTIL THE WELL RUNS DRY

Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters. Robert Glennon. Island Press, Washington, DC, 2002. 314 pp., $25.00 (ISBN 1559632232 cloth).

The sleight of hand that has kept the western United States growing in population and affluence depends on both physical and institutional arrangements that conceal the resource limitations of the arid West. Chief among these arrangements is the West's reliance on mined groundwater, because the patterns of usage it enables are heading for a reckoning. The eastern United States also uses prodigious quantities of groundwater, sometimes with problem-