

PHYSIOLOGY

All Fired Up: A Universal Metabolic Rate

What do an onion, a banana, a paramecium, and a person have in common? According to a study on page 2248, they—and all living organisms—share roughly the same resting metabolic rate when body size and temperature are taken into account. The finding suggests that widely diverse species burn energy in predictable patterns. “The [corrected] basal metabolic rate of an apple or tree is remarkably similar to that of bacteria, which is remarkably similar to a fish or person,” remarks lead author James Gillooly, a postdoctoral associate at the University of New Mexico (UNM) in Albuquerque.

“Biologists have realized for a long time that size and temperature affect metabolic rate,” but they haven’t known exactly how, says Karl Niklas, a plant biologist at Cornell University in Ithaca, New York. Niklas, who calls the new study “impressive,” says that “the mathematics has been elusive. This paper provides some very basic physiological equations to help clarify matters.”

What’s more, metabolic rate—how fast an organism takes in food or other material, uses it, and expels it—sets the pace for much of biological development. So the new model may help researchers predict how quickly a given creature will develop, reproduce, or die—based in part on how big and hot that creature is. Says Niklas: “Metabolic rate makes the machinery of life operate.”

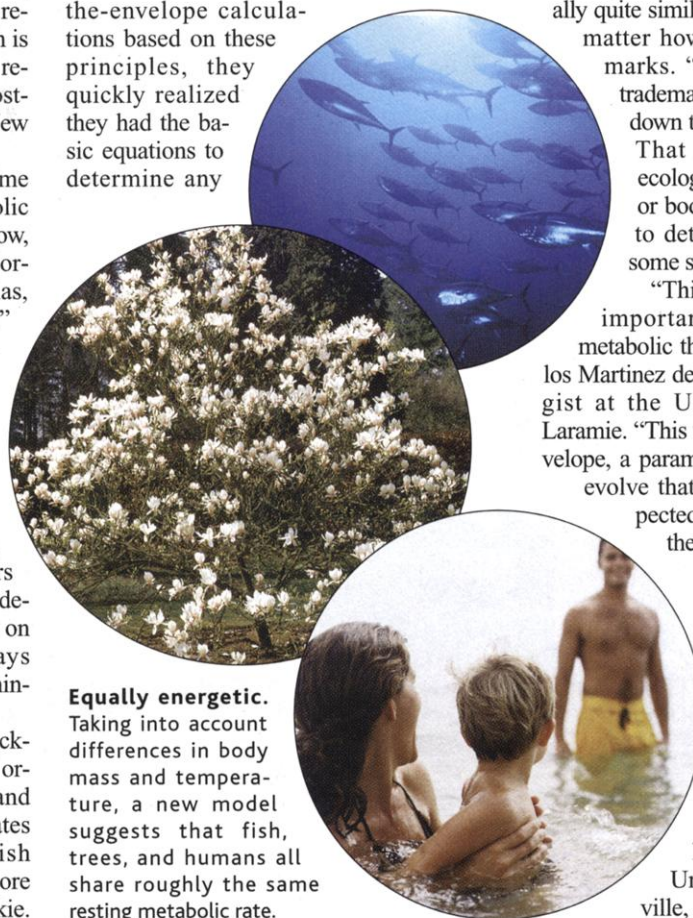
For decades, biologists have been clocking the widely varied metabolic rates of organisms. In general, they say, bigger and hotter species have higher metabolic rates than cooler, smaller ones—an Irish wolfhound, for instance, takes in much more food and produces more heat than a Yorkie. But pinning down this metabolic trend in quantitative terms has been tricky, partly because so many factors are at work.

One part of the problem—body size—came into focus about 4 years ago. At that time, UNM ecologist James Brown, physicist Geoffrey West of Los Alamos National Laboratory (LANL) in New Mexico, and biologist Brian Enquist, now at the University of Arizona in Tucson, devised a model to predict more precisely how metabolic rates increase in bigger species (*Science*, 4 April 1997, p. 122). That model uses the fractal geometry of circulatory networks, such as the vascular system, to explain the so-called quarter-power scaling law: the idea that metabolic rate varies in proportion to the $3/4$ -power of an organism’s mass. As body size increases, West says, metabolic rate rises in a predictable pat-

tern, such that nutrients travel as efficiently through a whale as though a shrimp.

Last year, when Gillooly joined UNM, he turned Brown and West on to temperature. Researchers have long suspected that rising temperature increases chemical reaction rates inside cells—and Gillooly’s recent graduate work hinted at just how strong this effect is.

Historically, metabolic rate studies have zeroed in on either body size or temperature. But why not put the principles of networks and reaction rates together? As the scientists scratched out some back-of-the-envelope calculations based on these principles, they quickly realized they had the basic equations to determine any



Equally energetic.

Taking into account differences in body mass and temperature, a new model suggests that fish, trees, and humans all share roughly the same resting metabolic rate.

organism’s approximate metabolic rate.

In the new study, the trio, along with UNM evolutionary ecologist Eric Charnov and LANL physicist Van Savage, fine-tune this model. When graphed on paper, the model plots metabolic rates adjusted for body mass—based on the fractal-based scaling model—against temperature. The scientists predicted that the data from any organism would yield a similar straight line with a universal slope based on chemical activation energies in cells.

To test the model, they plugged in published temperature, body size, and metabolic rate data for 250 far-flung species, including copepods, sycamores, bananas, peas, and fish, representing all major taxonomic groups across all biological temperatures.

And sure enough, each organism resembled the others—revealing a “universal” metabolic rate, says West.

The corrected metabolic rates of plants, for instance, are nearly identical to those of unicellular organisms and invertebrates such as yeast and zooplankton; they average just slightly lower than rates among endothermic birds and mammals. These findings stand in stark contrast to earlier, simpler models suggesting that metabolic rate can vary by a factor of at least 200. “In spite of its remarkable diversity, a unit mass of tissue is always actually quite similar in energy requirements, no matter how it has evolved,” West remarks. “You can boil much of the trademark variation in metabolic rate down to just mass and temperature.” That means other variables—ecological adaptation, for instance, or body composition—may do less to determine metabolic rate than some scientists believe.

“This group is doing something important: They’re constructing a metabolic theory of life,” comments Carlos Martinez del Rio, an ecological physiologist at the University of Wyoming in Laramie. “This work gives us a constraint envelope, a parameter space, in which life can evolve that’s more limited than we expected. All organisms must satisfy these basic biophysical laws.”

Del Rio cautions, however, that the universal metabolic rate model is a “broad-brush” description of life and that even when temperature and body size are factored in, organisms vary 20-fold in metabolic rate.

Brian McNab, an ecological physiologist at the University of Florida, Gainesville, agrees. He contends that the residual variation in metabolic rate holds biology’s most interesting stories of climate, diet, and bodily quirks. His research suggests, for instance, that island species have lower metabolic rates than their continental peers. “This is a valuable paper,” McNab says, “but there’s still a lot to learn here.”

Already, the study’s authors are expanding their work, predicting developmental rates in aquatic organisms, for instance. And their horizons may grow: The same basic physical principles that unravel metabolic rate in individual organisms could help track the turnover of nutrients, such as carbon, in entire ecosystems, Brown notes. “Once you have a fundamental sense of the combined effects of size and temperature,” says Brown, “it looks like you can account for an awful lot of biology.”

—KATHRYN BROWN