



Interactions between predators and prey, such as lynxes and hares, can be modelled with biological rules.

ECOLOGY

Biology distilled

Brian J. Enquist reflects on a blueprint to guide the recovery of life on Earth.

Can biology become as predictive as the physical sciences? And could it guide us in feeding the planet and reversing ecosystem degradation, climate change and species extinction? These are the overarching questions that organize evolutionary biologist Sean Carroll's *The Serengeti Rules* — a compelling read filled with big, bold ideas.

Biology is complicated. A cursory look at a diagram of the biochemical pathways in a cell or interactions between predators and prey in an ecosystem reveals myriad networks. Indeed, following the cascading effect of genes on a phenotype in or between individuals suggests that biological processes are almost unfathomably complex and idiosyncratic. Over the past two decades, those studying such systems have argued that most can be described as a network of interactions. However, this analogy, although powerful, does not necessarily tell us about the resilience of a given system. Nor does it reveal the generalities of the natural world and the regulation of genes, populations and ecosystems.

Carroll tells a richer story. He dispels the idea that biology is too complex to generalize or to become the basis of a predictive science. The book is really about the

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unification of biology that has occurred in the shadows of more well known work such as that by Charles Darwin, James Watson and Francis Crick. Through compelling storytelling, key insights of distant, isolated biologists are brought to life.

Carroll finds the common thread in discoveries in anatomy, physiology, gene regulation and cancer research. He does so by way of Nobel-prize-winning molecular biologist Jacques Monod, Janet Rowley, 'mother of chromosome genetics', and ecologists such as Tony Sinclair, who has helped to parse the ecology of the Serengeti region in Tanzania and Kenya.

Carroll distills this body of knowledge into principles. He argues that at all scales of organization, biology is regulated through axioms of interactions in networks — from the number of molecules in our bodies to the numbers and kind of animals and plants in and across ecosystems. He boils all of biology down to six rules of regulation (his



The Serengeti Rules: The Quest to Discover How Life Works and Why It Matters
SEAN B. CARROLL
Princeton University Press: 2016.

"Serengeti Rules"), which he shows are applicable both to the restoration of ecosystems and to the management of the biosphere.

The same rule may carry different names in different biological contexts. The double-negative logic rule, for instance, enables a given gene product to feed back to slow down its own synthesis. In an ecosystem the same rule, known as top-down regulation, applies when the abundance of a predator (such as lynx) limits the rise in the population of prey (such as snowshoe hares). This is why, in Yellowstone National Park in Wyoming, the reintroduction of wolves has resulted in non-intuitive changes in hydrology and forest cover: wolves prey on elk, which disproportionately feed on streamside willows and tree seedlings. It is also why ecologists can continue to manage the Serengeti, and have been able to 'rebuild' a functioning ecosystem from scratch in Gorongosa National Park, Mozambique.

Carroll argues that the rules regulating human bodily functions — which have improved medical care and driven drug discovery — can be applied to ecosystems, to guide conservation and restoration, and to heal our ailing planet. His *Serengeti Rules* encapsulate the checks and balances that minimize boom-and-bust cycles of species outbreaks and ecosystem imbalances. Ecological systems that are missing key regulatory players, such as predators, can collapse; if they are overtaken by organisms spread by human activities, such as the kudzu vine, a 'cancer-like' growth of that species can result.

Some of Carroll's recommendations are still being debated (see R. D. Grubbs *et al. Sci. Rep.* 6, 20970; 2016). Other pertinent work, such as findings by evolutionary ecologist Daniel Janzen on forest restoration, is already commonly used in conservation. Nonetheless, I suspect that many will find new insights and inspiration here.

Carroll has made a strikingly clear case that ecology is a science on a par with molecular biology and genetics. In many ways, this book is a homage to Charles Elton, who helped to define ecology as the study of species interactions in a 'trophic' network shaped by the environment (see E. Marris *Nature* 459, 327–328; 2009). Building on his vision, Carroll provides a passionate motto for the twenty-first century: "better living through ecology".

Are the *Serengeti Rules* a panacea? No, but Carroll convincingly reveals them to be a sturdy foundation for the future of biology, for human well-being, and for conservation and management. ■

Brian J. Enquist is in the department of ecology and evolutionary biology at the University of Arizona in Tucson, and is an external professor at the Santa Fe Institute in New Mexico.
e-mail: benquist@email.arizona.edu