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A LOOK AT THE EVOLUTION OF EVOLUTION

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There's More to Life than This

Viruses and the Evolution of Life. Luis P. Villarreal. ASM Press, Washington, DC, 2005. 395 pp., illus. $120.00 (ISBN 1555813097 cloth).

Are viruses alive or not? This question has plagued microbiologists since the discovery of viruses in the 1890s. Bereft of an innate metabolism, viruses may be viewed merely as chemical replication systems. But this would be a gross oversimplification, for viruses, like their cellular hosts, are at the mercy of Darwinian selection: they evolve. And it takes no great stretch of the imagination to see that viruses play some role in the ongoing evolution of their hosts. With powerful molecular tools at our disposal (many of them derived from viruses of bacteria), scientists have discovered an increasing number of genetic curiosities. Virus genes may be expressed by the host to increase host fitness, as is the case with *Vibrio cholerae* and its virus CTX phi (Waldor and Mekalanos 1996); host genes may be carried by a virus to increase its replication efficacy in a dying host, as is the case with some viruses of *Prochlorococcus* species that carry fully functional photosynthesis genes (Lindell et al. 2004). Given a mounting body of such evidence, "it is time to acknowledge and study the roles of viruses in the web of life, be they living or not." Such is the powerful opening argument of Luis Villarreal's new book, *Viruses and the Evolution of Life.*

This book provides a smorgasbord of food for thought for senior graduate students, professors, and researchers already engaged in the field of virology or phage biology. Villarreal assumes a lot regarding the viral savviness of his readers, so I would not recommend this text to anyone lacking a solid background in viruses. From the beginning, Villarreal establishes two ambitious goals: to examine the evolution of viruses from the perspective of the evolution of their hosts, and to consider the importance of persistent viruses in the evolution of life on Earth. He begins strongly, delineating a brief history of viruses, identifying broad patterns of virus–host evolution, and providing a clear definition of what he considers a virus: a molecular genetic parasite. This leaves the term "virus" open enough to include virus-like elements such as endogenous retroviruses and transposons, which figure heavily in Villarreal's arguments. Drawing on computer models, he argues for the likely early emergence of parasites (viruses) in informational systems, leaving the vast majority of evolutionary time open to viral influence. These models provide a clear illustration of how informational systems, biological or otherwise, cannot escape parasitization, and how this very parasitization is what drives increases in system complexity. A small problem I encountered with this argument is that throughout the text, evolution is equated with higher complexity; however, complexity is never adequately defined. Thus the reader is left to decide whether complexity pertains to genome size, to the number of organ systems, to the degree of homology to *Homo sapiens,* or to some other set of criteria.

This point aside, the book fulfills its goal of providing an overview of known virus–host interactions for most of the life-forms on the planet. Villarreal supplies a wealth of information on the relationships between virus and host, from prokaryotes to placental mammals, exploring the impacts and evolutionary implications of such interactions. Each chapter contains a thorough list of recommended reading and source material, enabling the reader to gain additional background or finer detail as needed.

The material on prokaryotes is particularly strong because of the comparative abundance of information on prokaryotic viruses, primarily bacteriophages. Villarreal provides a clear comparison of acute versus persistent replication routes, as well as their potential impacts on host fitness and evolution. He introduces significant examples of how viral survival mechanisms may affect prokaryotic evolution, such as addiction modules, which ensure stable and persistent incorporation of viral genomes within the host, and the replacement of host genes or genetic motifs (e.g., the origin of replication) with viral homologues.

Likewise, Villarreal provides especially coherent arguments for the role of endogenous retroviruses in the speciation of mammals and in mammalian features such as placental development and live birth. As a member of the Department of Molecular Biology and Biochemistry at University of California, Irvine, Villarreal has an established publication record exploring the effect of viruses on their mammalian hosts, particularly on the mammalian immune system and reproductive processes. Thus, when it comes to explaining how viruses could possibly play a role in the ability of placentals to carry an allogenic embryo internally without eliciting an immune response, Villarreal is in his element.

As this book led me through a menagerie of organisms and their multitude of viruses, I was presented with several new and fascinating examples of how viruses intervene in the evolutionary pathway of their hosts. One example is the linkage between sex and persistent viruses in protists. Because infected and uninfected partners cannot produce viable offspring, the population is segregated into two subpopulations that do not interbreed. The establishment of two such subpopulations is a key ingredient in the divergence of species, and this instance clearly shows how the process may be driven by viruses. Through arguments like this, Villarreal forces the reader to break out of the conventional disease and epidemiology mind-set and consider viruses in multiple contexts. In between prokaryotes and placentals, however, many of the arguments become

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weaker and more focused on single examples. Part of this is due to a dearth of information regarding viruses of other organisms, such as fungi, arthropods, crustaceans, and plants, especially compared with the volume of information available on virus–bacteria interactions. In Villareal's words, "viruses of [aquatic organisms other than bacteria] and their hosts present little apparent medical or agricultural risk; thus studies of them have generally not been well supported financially."

Beyond this logistical limitation, however, I found another, more serious problem with Villarreal's treatment of the material. Although he does a fine job in examining the range of known virus–host relationships across the domains of life, Villarreal does not always clearly establish the evolutionary significance of these relationships, and thus falls short of the second goal of his book: to weigh the importance of viruses in the evolution of life. Much time is spent reviewing what is known about viruses and their relationships with their hosts. While this background is certainly informative and necessary to a degree, I gained the impression that in the course of such exposition, Villarreal lost sight of his goal to elucidate how and where viruses influenced host evolution. This is perhaps symptomatic of a more overarching problem: the scope of the text seems a bit overzealous. In climbing the evolutionary ladder across all life from bacteria to humans, there was simply too much information to be covered in adequate detail. The result is that the book, at times, devolves into a capitulation of known virus–host interactions, without a clear synthesis of new ideas linking these interactions to concrete evolutionary events.

In spite of these shortcomings, Villarreal does ultimately make the convincing point that virtually every species on the planet is infected by viruses. And given the immense span of evolutionary time available, these viruses have probably played some role in tweaking the genomes of their hosts. In the final analysis, I can't help but agree with Villarreal: although the picture is still incomplete, it is time we include viruses in our conceptions of the tree of life, be they living or not.

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A LOOK AT THE EVOLUTION OF EVOLUTION

The Evolution of Darwinism: Selection, Adaptation and Progress in Evolutionary Biology. Timothy Shanahan. Cambridge University Press, New York, 2004. 342 pp. $80.00 (ISBN 0521834139 cloth).

Like many other scientists, I feel nervous when philosophers venture near my chosen field. I have nightmare visions of a formerly clear field of enquiry suddenly swamped in obfuscation, or drained of meaning by endless rounds of hairsplitting. So I approached this book, by a professor of philosophy at Loyola Marymount University, with some trepidation.

To my great pleasure, my fears proved to be groundless (in this case, at least). In *The Evolution of Darwinism: Selection, Adaptation and Progress in Evolutionary Biology,* Timothy Shanahan has written a clear examination of the development of a number of central ideas in evolution. He understands the science behind these ideas, and how the ideas have evolved as our scientific knowledge has grown. The result is a well-organized book that scientists can read and benefit from.

Shanahan deals with three main ideas: selection, adaptation, and progress. In each part of the book, a careful reading of Darwin and his contemporaries is juxtaposed with careful analysis of present-day evolutionists such as Richard Dawkins and Stephen Jay Gould. All the discussions are set in the framework of the overarching neo-Darwinian synthesis that was one of the great intellectual triumphs of the 20th century.

Darwin understood the full implications of his idea of natural selection, far more than did the codiscoverer of the idea, Alfred Russel Wallace. Wallace, in his original paper that forced Darwin to publish the *Origin of Species,* thought in terms of selection at the level of species. In Wallace's formulation, entire species would survive or go extinct as the environment changed, and as time went on the surviving species would diverge from each other. Darwin realized that natural selection acting on individual organisms can give rise to a far richer and more complex world, and Shanahan traces the implications of Darwin's insight.

Darwin pointed out that selection acting on individuals can bring about gradually increased adaptation when the environment is unchanging. It can also bring about physical and behavioral alterations when the environment is changing. Individual natural selection is happening all the time, regardless of whether or not the environment alters. Darwin also realized that sexual selection acts on individuals and can bring about remarkable changes.

Shanahan, like most others, distinguishes sexual selection from other types of natural selection. This distinction is commonly made because sexual selection for the ability to mate can act in opposition to other types of selection for abilities that allow survival. But this is a false dichotomy, because other types of natural selection can also act in opposition to each other. In the evolution of a predator, for example, power and speed, when taken to extremes, quickly become incompatible with each other. Thus, the distinctive difference between sexual and natural selection disappears, leaving us to conclude that sexual selection is a type of natural selection.

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Shanahan explores in detail the debate about individual and group selection. He provides a valuable summary of the work of V. C. Wynne-Edwards, who proposed that there must be some signal associated with crowding that leads crowded organisms to adjust their reproductive rates downward. The powerful counterargument to Wynne-Edwards's view, based on individual selection, is that a cheater who is unaffected by the signal will outreproduce other members of the group. Shanahan also examines the various types of selection for altruistic behavior, including mechanisms such as kin selection, which Darwin was the first to explore. He concludes, in agreement with current evolutionary thought, that while group selection may be important in instances such as the selection of virus populations in individual hosts, Darwin's insight that individual selection is overwhelmingly important still holds.

The second section of the book, on the changing meaning of adaptation, ventures further into the realm of the philosophical. Although Darwin fully realized that no organism can be perfectly adapted to its environment, he and his contemporaries were guilty of using the term "perfection" more often and more loosely than they should have done. It is clear, as Darwin gradually began to conclude through succeeding editions of *Origin,* that adaptation is not the only source of evolutionary change. Shanahan examines the tendency of evolutionists to construct just-so stories about adaptations, and the difficulties that have resulted, though he does not make the point (an important one, I think) that the proper way for science to proceed is to suggest a just-so story as a hypothesis and then to test it. The ability to test such stories, through clever field and laboratory experiments, is one of the ongoing triumphs of the neo-Darwinian synthesis.

Shanahan performs a valuable service by tracing the history of the question of what constitutes the unit of selection—the gene, the organism, or the population. He summarizes the arguments of many biologists that this, too, is an artificial division. If a chicken is an egg's way of making another egg, in Samuel Butler's memorable phrase, it is equally true that an egg is a chicken's way of making another chicken. Evolution cannot take place on genes in the absence of organisms, or vice versa, and of course changes in populations are the ultimate result of evolution. Shanahan summarizes: "Because biological entities are causally connected in complex ways, perhaps the only truly accurate account of natural selection includes biological entities and their causal interrelations at a number of different functional levels, and treats entire biological systems as subject to selective forces."

The last part of *The Evolution of Darwinism* deals with evolutionary progress. Just as Darwin tended to use "perfection" in a poetical rather than a scientific way, his writings are full of the use of the term "progress." But Shanahan, following in the footsteps of others such as Michael Ruse, shows clearly that Darwin was conflicted. He knew that simple organisms have changed very little since the beginning of life, so that any evolutionary tendency toward greater complexity has not affected them. And yet organisms such as humans are so complex, with so many new and emergent properties, that surely there must be some tendency toward the selection of such complexity under some circumstances.

The book's last section is an excellent summary of the conflicted thinking of many evolutionists about this question. But it does not quite come to a resolution. One can perhaps reach such a resolution by abandoning the term "progress" entirely. In the course of evolution, organisms simply adhere to the philosophy of Tammany boss George Washington Plunkitt, who memorably said, "I seen my opportunities, and I took 'em." The opportunities available to complex organisms have increased during the history of life—it is unimaginable that humans could have appeared, or survived, on Precambrian Earth.

This is a thoughtful and clearly written book that serves as a fine introduction to the ways in which evolutionary thought has itself evolved since the time of Darwin. I learned a lot from it, and I feel confident that anybody who is fascinated by these centrally important ideas will also take something useful away from it.

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HOPE FOR MIND ON EARTH

Earth System Analysis for Sustainability. Hans Joachim Schellnhuber, Paul J. Crutzen, William C. Clark, Martin Claussen, and Hermann Held, eds. MIT Press, Cambridge, MA, 2004. 454 pp. $38.00 (ISBN 0262195135 cloth).

This is a hopeful work. Hope shines through despite the litany of worldwide environmental worries that the book documents. Hope chimes out despite the conclusions of many contributors that the biosphere is so highly nonlinear and supercomplex that we—the human enterprise—will have to make tough decisions about the future in the face of tremendous uncertainty and limits to our analytic and predictive powers.

The volume is the edited product of a Dahlem workshop held in Berlin in 2003. Dahlem workshops gather top scholars for week-long interdisciplinary retreats that avoid formal presentations so that the 40 lucky participants can jump into the depths of their collective knowledge, using previously circulated position papers as springboards. Published papers resulting from these workshops are put through a rigorous review process, as are the group reports, which in this case are outstanding.

Readers of *BioScience* will be familiar with the title concept of sustainability, which Clark, Crutzen, and Schellnhuber, in the introduction, call the "most recent big idea in the history of the Anthropocene." ("Anthropocene" proclaims a new geologic epoch in which humans are a planetary force.) But what about the other term in the book's title, "Earth system analysis"? This conceptual frame-

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work treats the biosphere as a self-organized, interconnected whole that is simultaneously biological, chemical, and geological. What's new here, to my mind, is the full inclusion of humans (also called the "anthroposphere" in this book) within Earth system analysis. The result is a suite of papers that range from the origins of life and astrobiology to requirements for new forms of human institutions and, in a sense, even new forms of mind.

The four papers of the first section tackle such questions as these: Is life an inevitable planetary phenomenon? And what are the major transitions in evolution? The effects of life on the chemistry of the biosphere (or Gaia system) are seen primarily as by-products of local selection (Volk 2003). But as the evolution of new kinds of metabolisms affected the global chemical matrixes of air and water, these matrixes in turn affected the subsequent evolution of life. Uncertainties in dating make it problematic to discern causes and effects in the coordinated system of biological and geochemical events over Earth's history. Yet overall, the group report about this coordination, by British biogeochemist Tim Lenton and coauthors, is the best state-of-the-art statement I have read.

The second section focuses on the Earth system during the late Quaternary, a period that roughly covers the last of several glacial cycles of 100,000 years each. In the group report, led by oceanographer Andy Watson of the University of East Anglia, we are treated to a picture of the Quaternary Earth as a system as complex as any symphony, with harmonies played out by vegetation, carbon dioxide, methane, dust, ocean circulation, and other system properties that rise and fall (or fall and rise) along with the global ice sheets. But just as we stand in awe trying to imagine the process by which Beethoven or Mozart composed, so the experts stand in awe before the dynamic, cyclic Earth during the ice ages. Indeed, the group report concludes that a main lesson gained from scientific efforts to understand the Quaternary Earth as a system is that we are now "aware of our own ignorance."

Paul Falkowski and Dan Tchernov of Rutgers University take us headlong into the Anthropocene in the third group of papers, with their intriguing piece called "Human Footprints in the Ecological Landscape." It is perceptive of them to emphasize the awareness of death as a factor in the evolution of culture (Volk 2002), a factor still, of course, in play today. This, as well as several other factors they cite, such as the desire to accumulate wealth, may have created the high degree of human cooperation that has led to humanity's runaway success story. We now not only rival natural processes as a biogeochemical force, as detailed by other papers in this Anthropocene section. We also threaten the stability of those natural processes.

The book's fourth and final section moves into sustainability itself, and thus into issues such as the relationship of science to public policy, institutional reform, and crises caused by globalization's

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impacts on ecological interdependence. For me, one of the most interesting papers in the volume is Wolfgang Lucht's "The Mental Component of the Earth System." Lucht, at the Potsdam Institute for Climate Impact Research, proposes a "tetrarchical loop" between four mental components, which he calls GeoScope, GeoGraphy, GeoMind, and GeoAction. The loop involves large-scale social properties, such as observation and theory, knowledge and social contexts, governance, and identity (Lucht dares to suggest that we—again, the human enterprise—need to ask who we are and what we want to be in the future). Thinking about ourselves and using metacognition to examine the process of cognition is what truly made us, in an evolutionary sense, human (Terrace and Metcalfe 2005). If the unconscious coupling of desire and cognitive powers is a large contributor to global environmental problems, then becoming more conscious of our cognition and its effects is indeed what we need.

Environmental problems require mental solutions. We need to internalize the planet, to bring the biosphere home (Thomashow 2001). Developing metacognition on a global scale is also emphasized in the final group report by Arizona State University urban ecologist Ann Kinzig and coauthors, who use terms such as "global self-awareness" and "global will." Sustainability will require a complete Earth system analysis that takes into account not only biology, chemistry, and geology, but psychology and sociology as well.

Who is this book for? Who will benefit? Direct your favorite students, graduates, and bright undergraduates to this book and let them feast on their areas of interest. A few papers are too technical for anyone but disciplinary experts. Most, however, are excellent for an overview of a field, especially if you want to catch up on some ideas related to but not exactly coincident with your own.

In this book, great minds have assembled ideas into a system that reflects the complexity of the biosphere itself. Many of the authors reveal a sense of awe, humility, and concern, to which they have been led by their understanding. The mixture of expertise and emotion is heartening. The human mind is here on the physical Earth, and we can all hope it is here to stay. This can best be ensured by directing our minds to Earth as a field of knowledge—and to ourselves, because we are now part of the biosphere system. So doing will foster hope. In the closing words to this volume, our "dreams tell us not merely to persist but to thrive."

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FIGHTING TO STAY ALIVE

Striper Wars: An American Fish Story. Dick Russell. Island Press/Shearwater Books, Washington, DC, 2005. 288 pp. $26.95 (ISBN 1559636327 cloth).

Make way, Clive Cussler and Nevada Barr. In *Striper Wars: An American Fish Story,* environmental journalist Dick Russell writes a page-turner of a natural history tale every bit as suspenseful as the best murder mystery. In Russell's story, though, the victims are fish. And we're the perpetrators of the crime.

For the past 20 years, Russell has written books and articles on crises facing the world's oceans. A long-time sport fisherman, Russell is deeply involved in the battle to save the striped bass (*Morone saxatilis*).

In his latest book, Russell takes us into watery depths where striped bass have narrowly escaped death, not once, but several times. In the 1960s, striped bass in New York's Hudson River began to die by the millions. Dogged marine biologists and fishers-turned-investigators braved threats of bodily harm to find out why. The culprit turned out to be the water intake system of the Indian Point nuclear power plant, a finding that prompted a near riot and led to the cancellation of a proposed pumped storage facility at nearby Storm King Mountain.

By the 1980s, striped bass were in such decline that the fish seemed destined to join the bald eagle on the endangered species list. But through the efforts of fishers like Russell to curtail striped bass landings, a population estimated at about 4.6 million in 1982 reached a historic peak in 2004 of some 56.7 million fish.

The striper's remarkable, albeit temporary, comeback has become part of modern conservation lore. It's hailed from coast to coast as an example of a fish with a management plan that—for a while—worked: Stop overfishing, and the fishery will rebound.

Striper Wars: An American Fish Story is a behind-the-scenes look at what Russell calls "a story about a magnificent fish and those of us who have fought against commercial interests and government bureaucrats to bring it back from the brink." Although set mostly along the US East Coast (the "striper coast"), the book is also important reading for those concerned about threatened and endangered fish throughout the world's oceans, including cod, salmon, and all too many others. Chapters like "How the Striped Bass Stopped a Highway and Eluded the Mob," "Showdown at Friendship Airport," and "Revolt of the Biologists" introduce us to the villains and heroes of this piscine tale. Throughout, the striped bass themselves valiantly try to swim on, despite the political mongering taking place ashore.

From providing a mainstay in the diets of early Native Americans to inspiring the nation's first conservation law, striped bass have been part of our history. Indeed, stripers play an important role in human culture in river cities and coastal towns all along the Atlantic seaboard. Today, "to several million sport fishermen like me," writes Russell, "it is the premier game fish to pursue: intelligent, crafty, the ultimate challenge."

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Through Russell's fish-eye lens, we follow a female striper from her wintering home in waters off Cape Hatteras, North Carolina, to spawning grounds in the Chesapeake Bay. The fish journeys north along the coast to Long Island, past Narragansett Bay into Cape Cod Bay, and out to the Atlantic.

Russell longs for a time a half-century ago: "halcyon years, when a fisherman camped alongside the Cape Cod Canal could be awakened by the slapping of thousands of tails as an endless school of bass headed toward the open sea." Those years—and those fish—are gone.

In *Striper Wars,* Russell presents a case study in successful environmental activism. Lessons learned from the conservation of striped bass might be applied, he believes, to "today's critical questions of how to govern other fisheries, at a time when so many species are in grave jeopardy." Russell cites a landmark article, "Ecosystem-Based Fishery Management," published in the journal *Science* (16 July 2004), which states that fisheries management to date has often been ineffective. Ecosystem-based fishery management is a needed new direction, the 17 coauthors of the *Science* paper maintain: management priorities should be reversed, focusing first on the ecosystem rather than the target species.

Russell couldn't agree more. The striped bass is a prime example, he says, of a fish that's literally dying for want of ecosystem-based fishery management. *Striper Wars* shows us that we need to move beyond protecting a single fish to considering entire ecosystems in fishery management plans. And we need to get there soon.

Stripers are once again in trouble, their numbers declining. Once again, humans have resurfaced as the bass's foes. This time the crime is overfishing of the bass's primary food source—small, silvery fish called menhaden. "No longer is it simply a matter of overfishing [of stripers themselves], as it was in the past," Russell writes. "Now the struggle involves the life cycle of the fish and the realm of its inhabitants." A walk on almost any Chesapeake Bay beach proves Russell right: all along the shores are dead striped bass. Poor nutrition related to low numbers of

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menhaden in the bay is most likely to blame.

The relationship between striped bass and menhaden highlights the need for urgent changes in the way fisheries are managed, Russell argues. In a chapter titled "The Town that Menhaden Built," he takes us to Reedville, Virginia, and inside the menhaden factory of the Omega Protein Corporation, which processes Chesapeake Bay menhaden into feed for chickens, among other uses.

Describing the effects of the Omega operation, Russell writes: "I could think of no better definition for the phrase 'vicious circle.' The intricate web that nature has woven into and around the Chesapeake Bay ecosystem—where what happens to menhaden, algae [which menhaden eat], striped bass and chickens is all interrelated—human practices can rapidly rend asunder."

Obviously, the striped bass "still has something to teach us." Russell would have us heed its lessons and learn to make the right choices, as he did when he decided one evening to drive to a small harbor and release the striper he'd caught earlier in the day for dinner.

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NEW TITLES

The Archaeology of Global Change: The Impact of Humans on Their Environment. Charles L. Redman, Steven R. James, Paul R. Fish, and J. Daniel Rogers, eds. Smithsonian Books, Washington, DC, 2004. 308 pp., illus. $49.95 (ISBN 1588341720 cloth).

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