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LIFE IN THE BIOSPHERE

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How Predictable Is Evolution?

Singularities: Landmarks on the Pathway of Life. Christian de Duve. Cambridge University Press, New York, 2005. 258 pp. $48.00 (ISBN 0521841955 cloth).

The Belgian biochemist Christian de Duve won the Nobel Prize in Physiology or Medicine for the discovery of membrane-bound structures called peroxisomes and lysosomes within living cells. These tiny structures may be evidence of ancient endosymbiotic events, when two kinds of cell came together and combined their talents to take evolution in a new direction.

De Duve's interest in the origin of life and its subsequent history began with these discoveries, but it has not ended there. His new book, lucid and superbly organized, surveys the entire history of life, from the first protocells to complex multicellular organisms such as ourselves. *Singularities: Landmarks on the Pathway of Life* is filled with insights, and should appeal to all readers with a good grounding in biology and biochemistry.

The book is built around a useful classification of the different mechanisms that account for the singularities that have occurred during life's history. The first of these is deterministic necessity—life could have evolved in only one way. Another is a frozen accident—things are the way they are because of chance events that happened at the time of the singularity. And a third is fantastic luck—an event that happens with extreme rarity can catapult life in a new direction.

De Duve's classification scheme includes other singularities in which both chance and natural selection play a role. These consist of various kinds of bottlenecks: selective bottlenecks in which natural selection weeds out less fit lineages, restrictive bottlenecks in which conditions inside the cell or organism determine how evolution occurs, and a category that he calls "pseudo-bottlenecks," in which what we see is simply the surviving line of many lines that have been lost through chance or attrition. These, he argues, are the workhorses of the evolutionary process and account for the majority of life's diversity. It is usually impossible to distinguish between pseudo-bottlenecks and selective bottlenecks, but there must have been times during the history of life when both have played a role.

He also gives an amused nod to intelligent design. If life on Earth stems from the activities of some cosmic intelligence, then its features should reflect not the cumulative influence of natural selection, but rather the whim of the designer. Thus, if intelligent design is true, we can only hope that the designer was more intelligent than, say, the folks who designed the Edsel.

Life's origin is of course the elephant in the room—the biggest unanswered question in all of biology. We can trace all of the Earth's life to a common ancestor that probably lived about three billion years ago, but we can catch only glimpses of what life might have been like before that time.

De Duve examines the roles of biological singularities in the whole sweep of evolution. Much of the book is devoted to a careful examination of the singularities that might have led to the origin of life. Life's origin is of course the elephant in the room—the biggest unanswered question in all of biology. We can trace all of the Earth's life to a common ancestor that probably lived about three billion years ago, but we can catch only glimpses of what life might have been like before that time. What singularities took place?

Were there proteins (or some approximation of proteins) before there was genetic material, and if so, what role did they play? De Duve suggests, as others have done, that a variety of simple proteinlike compounds existed before there were any genes, and that some of these compounds had limited catalytic capabilities. But he does not explore how these molecules might have been organized so that that they could carry out a series of biochemical reactions efficiently. It seems unlikely in the extreme that any one protocell could have had more than a handful of such primitive proteinlike catalytic molecules, and they would have been diluted by a freight of other molecules that weren't much good for anything at all.

Was there natural selection before any genetic material? If so, what was selected? And how could the advantageous characters of a gene-free protocell have been passed down more than a generation or two before being diluted out? De Duve does not confront this latter question directly, but it lies at the heart of scenarios for the origin of life.

Was RNA the first genetic material? And if so, where did it come from? Adenine and the other nitrogenous bases have been synthesized under conditions that might have been locally present on the early Earth, but as de Duve points out, we are totally mystified by how nucleotides might have appeared.

What were the first energy-utilizing pathways? Glycolysis and the Krebs cycle, or electron transport supplied by energy-rich molecules such as hydrogen sulfide and driven by proton gradients across a membrane-bound vesicle? De Duve votes for glycolysis, while Jeff Bada and I have voted for a simple form of electron transport, but it is impossible at the moment to decide which, on the basis of phylogeny, could have come first. Both scenarios have huge problems.

De Duve also examines what phylogenetic analysis can tell us about later singularities, such as the origin of eukaryotic cells and the origins of chloroplasts and mitochondria. His discussion of these matters, about which we have a

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good deal more evidence than we do about the origin of life, is extremely cogent and interesting. He traces the possible scenarios for eukaryotic cells' acquisition of mitochondria, giving a balanced view that includes possible multiple origins for the hydrogenosomes that are derived from mitochondria, and raises the question of how mitochondria might have survived in eukaryotic cells before there was enough free oxygen for them to carry out their current functions.

De Duve's book is always logical and balanced, and it is scrupulously fair to all the workers in the field. There are, of course, many other things I would have enjoyed having him discuss. For example, while we can only speculate about the singularities of the distant past, it may be possible to examine singularities in present-day experiments on the origin of life. Imagine a chip with thousands of little wells, each occupied by a tiny membrane-bound protocell incorporating different combinations of proteinoids and nucleotide building blocks. Present-day technology, using light-emitting reactions, would allow the experimenter to pick out the protocell that was most efficient at making ATP from ADP, or making a dipeptide from two amino acids. Multiplication of that protocell and transfer of its daughters to a new set of wells might allow us to find out if Darwinian selection can take place even without the aid of genes.

Once or twice de Duve reveals his regrets that more experiments are not being done to investigate such processes. And he makes one giant prediction: He claims that prebiotic chemistry has a large component of deterministic necessity and that life on other worlds will be found to resemble ours closely at the biochemical level. We may soon see how this prediction pans out.

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LIFE IN THE BIOSPHERE

The Human Experiment: Two Years and Twenty Minutes Inside Biosphere 2. Jane Poynter. Thunder Mountain Press, New York, 2006. 354 pp. $26.95 (ISBN 156025775X cloth).

Scientists and the general public alike have long been conflicted over how to view Biosphere 2, the controversial experiment in space living and the would-be research center in the high Sonoran Desert north of Tucson, Arizona. Was the Biosphere, which is now up for sale and sits empty (except for a small staff and the occasional tourist), a noble effort at a hippie-like alternative lifestyle, a religious cult living in its own fantasy world, or an important test of whether humans could live in space colonies?

Actually, a little of all three, writes Jane Poynter. But more important, Poynter gives us some insight into how a group of normal, intelligent, self-motivated people respond to living for an extended time in close quarters within an enclosed structure that is cut off from the outside world—in other words, just the sort of conditions space colonists are likely to face on the moon or Mars or other alien worlds.

The Biosphere was a test of whether humans could live for an extended period in a completely enclosed ecosystem, growing their own food, breathing recycled air, and reusing water. Poynter states, "We were pushing the limits of the science and the technology of the time.... We were attempting the impossible." They were "ready to make history."

Poynter calls the Biosphere experience as "an extraordinary adventure" conducted by "a colorful band of mavericks." As one of those mavericks, Poynter describes herself as a then 30-year-old woman from a well-to-do family, "a snooty English girl with high spirits, a decent intellect, and an appetite for learning and doing." She recounts writing and acting in plays in New Mexico, sailing on a ferroconcrete research ship in the Indian Ocean, diving in the Caribbean Sea, and living in the Australian outback. All of that served as training and a rite of passage for learning how to deal with isolation, handle stress, and develop an ability to depend on others—all skills that would be required for living in the Biosphere.

Poynter recalls the excitement, reverence, and "arrogance" with which she and her fellow biospherians looked forward to living in the Biosphere. "We never suffered a shred of doubt," she says. "I wanted to be part of something bigger than me," she remembers, something historic. She saw the experience as "transforming," a chance to "prove my character, my resourcefulness."

But soon after the eight volunteers entered the Biosphere on 26 September 1991, problems arose. Over the ensuing months, carbon dioxide levels rose, then fell, rose again, and finally were brought under control. Meanwhile, oxygen levels dropped, sometimes resulting in headaches, shortness of breath, and other physical maladies for the biospherians. The food supply, which was intended to be grown mostly within the Biosphere, fell short and became somewhat monotonous when blight, insect pests, and disappointing harvests struck. The result: Persistent hunger and weight loss among all the biospherians.

Meanwhile, insects invaded the supposedly airtight structure. Ubiquitous ants killed off most other insects intentionally brought into the Biosphere, and cockroaches turned kitchen counters brown at night. Furthermore, what was launched to rave reviews by the news media turned into one negative story after another about air leaks, hidden data, food and other goodies being smuggled in, and biospherians sneaking out for pizzas ("If only we had!" Poynter laments).

More seriously, Poynter recounts the personal disputes and antipathies that soured relations between Biosphere managers and participants, between managers and outside scientists, and even among the biospherians themselves. As problems accumulated, she says, tensions rose, along with a sense of secrecy and mistrust. The participants came to be divided into "Them" and "Us," with the two groups hardly speaking to one another. When they did speak, loud, often

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acrimonious arguments ensued. At one point, Poynter recalls, other biospherians spat at her.

The Biosphere's managers exacerbated those disagreements. Poynter describes John Allen, the group's founder and the project's leader, as an inspirational but at times domineering and mean person who wanted total control. They were "going down a well-documented path," Poynter writes, in which "noble ideas with a powerful visionary to guide their execution become dogma and the leader becomes increasingly dictatorial."

Nevertheless, the Biosphere experiment included more than 50 research projects, most conducted in collaboration with scientists from Columbia, Yale, Georgetown, Arizona, and other universities, as well as the Smithsonian Institution. Still, when the Biosphere's managers were unable to produce a plan for scientific research, the group's science advisers all resigned. They included such respected scientists as Tom Lovejoy, Stephen O'Brien, and Eugene Odum. Their resignations, in turn, led to a loss of scientific credibility that, Poynter says, "damned the project."

One lesson that Poynter learned (and perhaps our urban society should relearn) is that farming is "bloody hard work." The team member in charge of agricultural production, she reports often feeling dragged down by the myriad chores involved in planting, growing, raising, harvesting, and preparing food for everyone. The work often left her feeling tired and with little energy left over for creative activities or thought.

In the end, at least one question remains. Was the Biosphere project worth the effort, the cost ($150 million), and the personal acrimony? Yes, Poynter emphatically states. All of those involved in the Biosphere had collectively developed a concept, built a structure that not only worked but won numerous architectural and other awards, and learned how to operate it in the blazing heat of the Arizona desert. Food shortages and weight loss aside, the biospherians grew all of their own food and completed their two-year experiment in good health. No one left the facility early except Poynter, who had to seek medical help after part of her finger got sliced off in a rice thresher. She returned to the Biosphere a few days later.

But the question of the project's success or failure, Poynter points out, should not rest on whether the goal of sealing people inside the Biosphere for two years with nothing leaving or entering was achieved. Rather, the project should be seen as an experiment from which something is learned.

"What is most important," Poynter concludes, is to "dream crazy dreams and to work like hell to realize them." "We had attempted something entirely new.... Our technology was sound, the idea was noble, the project was visionary and courageous, but simple human frailty brought the walls crashing down.... It seems impossible to convey the severity of the psychological and social challenges in isolated and confined environments."

Finally, Poynter says, the Biosphere remains "a monumental testament to the human spirit.... And if I had to do it over, I'd do it in a heartbeat."

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THE WORM TURNS

Invertebrate Conservation and Agricultural Ecosystems. T. R. New. Cambridge University Press, Cambridge, United Kingdom, 2005. 368 pp., illus. $120.00 (ISBN 0521825032 cloth).

In the first issue of *Conservation Biology,* E. O. Wilson described insects as "the little things that run the world." Despite this insightful aphorism, the field of conservation biology continues to be dominated by larger animals, especially mammals and birds. However, the worm may be turning, so to speak, because appreciation of the importance of conserving invertebrates—a group that encompasses 99 percent of animal diversity and performs many vital and irreplaceable ecological functions—has grown steadily over the past two decades. Timothy New makes a major advance in educating the public and his peers on this topic in his new book, *Invertebrate Conservation and Agricultural Ecosystems.*

Conservation biologists have traditionally eschewed managed areas, considering them to be ecological deserts representing only the demise of more pristine natural ecosystems.

Having ridden into the breach of one of conservation biology's deeply ingrained proclivities, the predilection for fur and feathers, New takes on the other, the preference for "wild" areas over managed ones. Conservation biologists have traditionally eschewed managed areas, considering them to be ecological deserts representing only the demise of more pristine natural ecosystems. On the other hand, specialists charged with managing land for commodity production often view conservation concerns as constraints to the range of tactics that can be employed for the management of pests and other problems. This text provides the most convincing and detailed case to date that a vast amount of diversity exists and can be conserved in agricultural systems and, conversely, that pest managers can greatly benefit from the lessons learned and techniques employed by conservation biologists. Both of these groups, along with anyone else with even a tangential interest in the management of invertebrate populations, will benefit greatly from this new text.

New's background and accomplishments make him uniquely qualified to take on the ambitious scope of this book. By almost any measure, he is one of the major forces behind educating other scientists and the public in general about the conservation of insects and other invertebrates. In addition to authoring more then 20 books, including several key texts (e.g., *An Introduction to Invertebrate Con-*

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servation Biology and *Butterfly Conservation*), New, a reader and associate professor at La Trobe University in Melbourne, Australia, has published over 350 research papers and is the editor of the *Journal of Insect Conservation Biology.* In recognition of New's efforts, the Royal Entomological Society awarded him the Marsh Christian Trust award for insect conservation.

The book contains 10 chapters that fall into four general categories. The first three chapters cover the basics of agroecology, comparisons of natural and managed ecosystems, and the importance of managed areas for conservation.

Chapter 1 provides an excellent overview of key topics in just 17 pages. Although many of these topics are reiterated or treated in greater detail later in the book, this stand-alone chapter will be widely used because of its portability. Large portions (if not the entire text) could be required in courses on conservation, but I can envision assigning this chapter in my course on pest management, too. This is the first offering I have seen that fills that void for pest-management students, who represent a large audience not often exposed to cogent material regarding conservation.

Equally impressive in this section is chapter 2, which focuses partly on the important functions that invertebrates perform, namely, the services they provide in agroecosystems. Almost by definition, the species that provide meaningful levels of services are not truly rare (although they are often in decline), so they are usually overlooked as targets for conservation. I would have liked to have seen an entire chapter devoted to this topic, but the introduction provided in chapter 2 is well done, and specific services (especially pest suppression by predators and, to a lesser extent, pollination and dung decomposition) are revisited in later chapters.

With the stage set by the first two chapters, chapters 3 and 4 provide the punchline—a review and synopsis of the impact of agriculture on biodiversity. I found chapter 4 one of the most thought provoking because it went beyond just logically presenting accepted agroecology dogma—which is useful in itself—and took the bold step of questioning some of the field's commonly held tenets and providing counterexamples to them. Like chapter 1, the first four chapters together form a stand-alone unit, providing a solid foundation on their own and greatly enhancing the effectiveness of the later chapters.

Chapters 5 and 6 move on from the broader overviews to focus specifically on biological control, the manipulation of natural enemies (e.g., predators) to suppress pest populations.

Chapter 5 focuses on "classical" biological control involving the importation and establishment of natural enemies to control exotic pest species. The literature here is vast, and New does an admirable job of pulling it together. Whole texts have been written on this topic, but often a more concise treatment is needed, and this chapter definitely fits the bill.

Chapter 6 focuses on cultural control, the manipulation of the environment to minimize damage caused by pests through reduced rates of colonization, feeding, reproduction, or survival. The primary tactics featured are those that seek to reduce pests' survival rates by increasing the densities of natural enemies or facilitating their effectiveness. This suite of tactics, often termed "conservation biological control," has a clear link to conservation biology, as beneficial species performing a valuable service are being conserved. The link back to "other invertebrates," those that are not natural enemies of pests, does not appear until two chapters later, however; although it is well done, it seemed slightly disjunct. Also, it seems to imply that conservation of these other invertebrates is something that goes on outside the managed area, and I am not convinced that this is the case, since a distinct flora and therefore fauna occurs inside the field. Nonetheless, the section is comprehensive and does integrate well where it stands, so it may represent merely a deviation from my own organizational scheme.

The next two chapters deal with ecology and conservation outside the focal managed area. Chapter 7 deals with issues in areas directly adjacent to crop fields (field margins), and chapter 8 addresses issues pertaining to larger geographic areas and those farther from the field edge (landscapes). Following from the previous section, these chapters are largely concerned with conservation biological control, but other invertebrates are also addressed and complex issues involving longer-range movement, including metapopulation dynamics, are extremely well integrated here.

The final two chapters are stand-alones. Chapter 9 deals with a specific system—grasslands—and I agree that these more perennial systems are distinct enough to warrant their own chapter. It occurred to me that many parallels exist between grasslands and other nonannual systems, such as orchards and even ornamental areas (e.g., road margins). Forest areas are dealt with in the final chapter, but I feel that although they are clearly unique, there would be some synergy in integrating them here. I would (self-servingly) like to call for these other systems to be integrated into this chapter and receive the same thorough treatment in the next volume. The final chapter is eclectic but effective, and explores topics ranging from landscape structure to the implications of biotechnology. This final offering provides an appropriate capstone to a thorough and captivating text.

I will admit to having long been a fan of New's publications. I have used his texts extensively in the courses I teach and as valuable resources in my research program. This book has all the attributes that have made his others so enduringly useful. Other similar texts often fall into one of two traps: Either they provide a solid logical framework but very little connection to current literature, or they degenerate into essentially annotated bibliographies and provide very little, if any, framework. New integrates vast amounts of literature and provides a synoptic whole that is far more valuable than the sum of its parts. The reader is presented with both important, unique insights and a roadmap to the research findings on which they are based. All of this is presented with high-quality figures and tables that are particularly valuable for sharing with students because they facilitate understanding of the concepts.

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I am confident that this text will be a central reference for anyone working in, or interested in, both conservation and agriculture. I hope it will captivate others with the challenges and opportunities that await them.

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NEW TITLES

Aldo Leopold's Odyssey. Julianne Lutz Newton. Island Press, Washington, DC, 2006. 504 pp., illus. $32.95 (ISBN 1597260452 cloth).

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