Some Things I Learned from Lynn Margulis

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The first time I saw Lynn Margulis speak was about 1980 at University of Rhode Island – where I had begun studies in mathematics along my path toward a PhD in ecology and evolution. I had heard of her, but knew little about her work. I attended her lecture in a packed lecture hall, forced to stand where I could barely see her images of squirming microbes. But to some extent, I didn't need to. Her vivid verbal descriptions were almost enough; her energy and enthusiasm lit my world. I immediately wanted to know more about this person. And what's this she was saying about how eukaryotic cells had evolved from ecological consortia among bacteria? Whoa! That was crazy. I was hooked. I wanted to know more.

But life intervened to postpone my study of her work for two decades. My doctoral studies at the University of New Mexico did not allow time for microbes and cell evolution, but it did lead to an overlap with Lynn's work. My dissertation research focused on a famous symbiosis — an ecological interaction between species that remain in close physical contact for a substantial part of their lives — between plants of the genus *Yucca* and moths of the genus *Tegeticula*, the 'yucca moths'.

Theirs was an ‘obligate mutualism' because neither could reproduce without the other. Adult female moths are yucca's only pollinators. They lay an egg in a flower's carpel (the part that becomes fruit), then climb to the stigma and actively push pollen – carried under their head in a ball after collection from previously-visited plants — into the style with modified mouth parts. Their eggs hatch in the developing fruit and her larvae feed on seeds, after which they burrow out of the fruit, fall to the ground, and hibernate (diapause) in the soil in a cocoon of silk and sand until a future flower season, often years later.

I examined two components of the symbiosis: coordination between adult moth emergence and flowering in the highly-variable annual precipitation of the desert, with very little flowering in dry years, floral explosions in wet ones; and selective fruit abortion by the plants. My research showed that 1) moth adult emergence is strongly correlated with annual rainfall which they use as a cue for continued hibernation or emergence; 2) that it matters from which plants momma moth collect pollen; and 3) that yucca 'prefer' pollen mixes from several donors.

For six years, I performed field experiments at a desert wildlife refuge — Sevilleta — straddling the Rio Grande. I spent up to three months each summer living out of the back of my pickup. I had lots of time to think during the heat of the day while sheltering myself in precious little shade.

Several radical — for a grad student — ideas entered my thinking then, all of which were congruent with Lynn's teachings, as I would learn later. First, those two species are effectively one since neither can complete sexual reproduction without the other. That challenged my understanding of the species concept.

Second, the word 'mutualism' – which Lynn didn't like — was often oversimplified as a “win/win” (or “+/+” in biology texts) in which species “help” each other, unlike “-/-” of competition or the “+/-” of predation and parasitism. Yet this mutualism has negative elements: moth larvae eat many seeds, and yuccas aborted fruits sired with undesirable pollen (and other factors related to moth behavior). Their relationship — which had evolved from parasitism — is less like a happy marriage than a war with an agreement to limit damage to tolerable levels.

Third was about fitness, a measure of an organism's probability of survival and reproduction, often tied to a trait or a gene variation. After much reading and thinking about how to measure the fitness of moths and yuccas that are so intertwined, I learned that one cannot empirically measure fitness easily, if at all. That felt like a crack in the foundation of evolution theory: if one cannot accurately measure fitness in a quantitative way, then is evolution really science, or merely a philosophy driven by “just so stories”? The latter is the name that evolutionist and author Stephen Jay Gould gave to speculation presented as an explanation of why natural selection would favor specific characteristic of organisms, as if every structure — the shape of an ear, for example – has a purpose that is molded to perfection.

Fourth, I learned that symbiosis plays a larger role in ecosystems than admitted by the masters of competition theory, one of whom — James Brown — challenged that assertion from his front row seat at my dissertation defense. But I finished strongly because of a well-written and -rehearsed presentation with logical conclusions based on good experimental design, solid data and analysis aided by an MS in probability theory and statistics.

Contrast that with my doctoral oral exam two years earlier, three of the most terrible hours of my life during which neo-Darwinian professors grilled me about fitness, inclusive fitness, cost/benefit analysis, altruism, and

group selection. My answers to their questions demonstrated that I didn't really understand those concepts; in retrospect, they didn't make sense to me in a neo-Darwinian context. I was sentenced to more study to atone for my sins. I felt embarrassed, even guilty. But I survived and moved on.

After earning that diploma, I considered tenure-track research positions at college and applied for a few, but took a full-time community college teaching position instead because teaching is a much greater passion for me than research. I taught mostly biology with a focus on cells, physiology, evolution and "environmental" sciences. [I no longer use the term "environment", preferring to acknowledge that we are surrounded by and living within Gaia, an effectively living planet.] And there in my texts were Lynn's ideas about the origins of mitochondria and chloroplasts, even if they still labeled undulipodia like cilia and sperm tails as "flagella" (which are bacterial structures) and made no reference to their spirochete origins. Questions that she fielded after her 1980 lecture in Rhode Island indicated that she was still struggling for acceptance of her ideas, but by the 1990s, she had clearly made it.

In 1997 came her book *Slanted Truths: Essays on Gaia, Symbiosis and Evolution*. I devoured it. By far the most important chapter for me was chapter 20, "Big Trouble in Biology", in which – with justifiably righteous vengeance — she challenged neo-Darwinians on their unsupportable views on fitness, inclusive fitness, cost/ benefit analyses, and other unmeasurables, unlike the measurable quantities of physics like mass, volume and energy. She called them "priests" in a "neo-Darwinian religion" who forced their students to recite the "liturgy" of their often unsupportable dogma, as I had been required to do. While reading that chapter, I literally cheered and danced! I felt vindicated because she helped me understand that at least some of the concepts that I was grilled on during my doctoral oral exams were fundamentally flawed.

Lynn instantly became my hero, and I schemed about how to weave more of her ideas into my courses at the college. Reading more of her struggle as a scientific underdog to have her ideas even considered — let alone accepted — increased her hero status in my mind. I wanted to study with her. But how? I wanted no more diplomas, and I was a teacher, not a researcher.

That year, I inherited money from a distant relative. I used it to model my vocation after James Lovelock, an independent researcher, but I became an independent educator. I quit my job at the college and migrated to the Pacific Northwest where I founded a small, independent, non-accredited (by choice) school called Euglena Academy. It was housed in a decked-out warehouse — a San Francisco style loft space with couches, wood stove, kitchenette, and projection equipment — where I offered courses about ideas that I had become passionate about during self-guided post-doc studies in systems sciences, including chaos theory (nonlinear dynamics), fractal geometry, self-organization in dissipative systems, emergence theory, autopoiesis theory, symbiogenesis and Gaia theory, along with courses on biology and abrupt climate change.

My students received no degree or diploma, but studied for the joy of learning radical new ideas that were not part of their formal education. My program was motivated in part by my conviction that a deeper rational and intuitive view of life and Gaia from a systems perspective is necessary for our species's survival.

I developed and taught over 20 courses, from introductory — for those no background in science — to advanced, suitable for PhD's and science professionals. As texts, I used books by Ilya Prigogine, Harold Morowitz (*The Emergence of Everything*), Stephan Wolfram (*A New Kind of Science*), Franklin Harold (*The Way of the Cell*), Ricárd Sole and Brian Goodwin (*Signs of Life*), James Lovelock (*Gaia: The Practical Science of Planetary Medicine* and *The Revenge of Gaia*), Per Bak (*How Nature Works*), Dorion Sagan's *Into the Cool: Energy Flow, Thermodynamics and Life* (with Eric Schneider), and — of course — several books by Lynn, most with Dorion.

In the early years of Euglena Academy, Lynn and Dorion came to Portland, Oregon to speak. A dozen of us from the academy went to hear them. After their presentations, we became Margulis groupies, crowding the stage, hoping to say hello. Afterward, during drinks at the hotel next door, we realized that they were sitting in an adjacent ballroom at a fund-raising dinner. Lynn came out to go the restroom. On her way back, one of my students boldly approached her with a question about his future studies. To our surprise, she graciously engaged him for about five minutes.

Two years later, I sent her a letter about Euglena Academy, telling her that I was teaching courses using her and Dorion's books *What is Life?, What is Sex?, Early Life, Acquiring Genomes,* and *Into the Cool*. Within days I received a phone call from her about how delighted she was that an independent educator was teaching her work.

In 2008, she came to Salem, Oregon, to speak. Again, my students and I went to hear her. That time, I arranged a meeting with her. Our connection was immediate and comfortable. I updated her about new courses in my curriculum. She filled me in on her latest work on spirochetes and making many reading suggestions. I took about 8 pages of notes. At the end of our hour, she invited me to join her for her next interview, after which, she

said to me, “You'll join us for dinner, won't you?” You can guess my response. I sat by her, eating fish right off her plate after she said, “I've got too much food and this looks better than what you ordered.” While others at our table talked among themselves about the tribulations of their day at work, she and I discussed my dissertation work on the yucca symbiosis among other topics. After dinner, she offered a presentation to a couple of hundred people with the same animation and enthusiasm that I had seen in 1980.

Participants at Euglena Academy ranged from physicians, medical examiners, biochemistry graduate students and professors to insurance brokers, realtors, carpenters and artists. Regardless of background or vocation, courses about Lynn's work were among their favorites. Yet attracting students who were busy with careers, families and mortgages to a school that offered no diplomas was challenging. And by 2010, my quasi-nomadic nature was restless. So after a decade, our board of directors and I closed the academy and I moved to Maine for several reasons, one of which was to be closer to Amherst. [My program that I called Euglena Academy in Oregon has been renamed Ermah Ge. Ge is the most ancient name for Gaia; Ermah is an acronym for **E**a**r**th’s **m**etabolism **a**nd **h**omeostasis, the simplest explanation of Gaia. Our web site is www.ermahge.com.]

I wrote to Lynn about my move. Days later, she called and said, “Come to Amherst and take my summer course called 'Reel Life' about using videos to teach biology.” So in early August, 2010, I rode buses from Maine to Amherst, then walked the few blocks to her house. Her dog, Menina, greeted me with a wagging tail. I climbed the stairs to the back porch and raised my hand to knock, but before my hand hit the door, her voice hailed from the kitchen where she was preparing our evening meal. “Come in! I hope you're hungry!”

So there was my hero, the person I consider to be the most important biologist of our time, Charles Darwin's equal in my view, cooking my dinner. I struggled to keep my feet on the floor while helping her cut vegetables from her garden. Her other house guest – a kind and interesting post doc from Italy - joined us for dinner. The three of us ate while discussing Gaia, mitochondria, gardening, languages and music. And that was just the beginning. More dinners and breakfasts followed. “Take some stew, fruit and cheese for your lunch”, she'd say as she rushed off to her lab after breakfast.

How do I define intellectual heaven? Three weeks of daily classes with Lynn offering personal narration of videos about *Amoeba*, *Paramecium*, *Euglena*, *Stentor*, *Ophrydium*, *Mixotricha* and all manner of other microbes; helping organize thousands of her images into a new data base; returning to her house for dinner; then sitting on her back porch (next door to Emily Dickinson's house) eating breakfast with her while discussing the latest evidence supporting the spirochete origins of undulipodia.

At the end of my visit, she hosted a class party that included a going away element for me, complete with a carrot cake with vanilla icing inscribed in chocolate with microbes and the words “Au revoir, Alder”.

I was deeply honored.

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I'll end this essay with several quotes from Lynn's books that have had a great influence on my understanding of evolution, life and Gaia.

The first is related to an argument advanced by numerous historians and philosophers about the negative consequences of humans viewing and treating “nature” as a “machine”. In my courses, I explicitly distinguish between mechanistic reductionism and a systems view of life, refusing to use the word “machine” or “mechanism” in reference to life. In this passage, she explains why those are inappropriate metaphors for life.

> “The world as a vast machine fails to account for our own self-awareness and self-determination because the mechanistic worldview denies choice. Mechanisms, after all, don't act; they react. And mechanisms, moreover, don't come into existence on their own. The assumption that the universe is a mechanism implies that it was made according to some human-like design – that is, by some living creator. In other words, successful as it is, the scientific mechanistic worldview is deeply metaphysical; it is rooted in religious assumptions.”
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> Lynn Margulis and Dorion Sagan. 1995. *What is Life?* University of California Press. p. 7.

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My second quote is from the same book. It succinctly intertwines the concepts of Prigogine's self-organization in dissipative systems with metabolism as the chemical manifestation of the more abstract concept of

autopoiesis. The latter, a concept developed by Humberto Maturana and Francisco Varela, means "self making" or "self-creating", and is characterized by systems that are self-organizing, self-maintaining, self-repairing, and self-bounding. I had studied autopoiesis for years, but never fully grasped the concept until reading this. I've *italicized* the clause that made the abstraction of autopoiesis finally 'click' for me by equating it directly with metabolism.

> "Dissipative structures, chemical systems that use streams of energy to increase their internal order, are, however, rare and short-lived. But if the increased internal order is that of life, then, given access of the system to a source of energy and the right kind of matter (nutrients), it maintains indefinitely. This is autopoiesis. Autopoiesis is what happens when a self-bounded chemical system – based not on small molecules of sulfuric and malonic acids [as in the BZ reaction explained earlier in the chapter] but on long-molecule nucleic acids and proteins – reaches a critical point and never stops metabolizing.
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> "Metabolism, the chemical measure, *the specific earthly manifestation of autopoiesis,* has been a property of life since it began. [Italics mine] The first cells metabolized: they used energy (from light or from a small range of chemicals – never from heat or mechanical movement) and material (water and salts, carbon, nitrogen, and sulfur compounds) from outside to make, maintain, and remake themselves. Autopoiesis, the chemical basis for the impatience of living beings, is never optional. Absolutely required at all times for any life form in a watery milieu, autopoiesis, once it appeared in the tiniest bacterial ancestor, was never completely lost."
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> Lynn Margulis and Dorion Sagan. 1995. *What is Life?* University of California Press. pp 76-77.

In my courses, I strive to help my students gain a conceptual understanding of biological processes more than laboring to grasp biochemical details. Lynn had a way of cutting through the complexities of biochemical details to summarize the take-home point. Here is an example from her condensed yet information-rich *Early Life*, the text for one of my courses. This passage about the evolution of electron transport systems is from ten pages that include the origins of and linkages between several major metabolic concepts that I've never before seen explained so succinctly: fermentation, nitrogen fixation, ferredoxins [iron sulfur proteins] and porphyrin rings. The iron and sulfur are important because of their relationship to one of the two currently most compelling models for the origins of life on Earth that involve FeS, iron sulfide, aka "fools gold".

> "… desulfovibrios [a bacterium] reduce sulfate to sulfide and water, and they oxidize certain molecules in the fermentation pathway. High-energy electrons (or hydrogen atoms) do not pass directly from the oxidized organic molecule to sulfate, but move gradually along an electron-transport chain – a sort of bucket brigade of molecules that are capable of reversible oxidation and reduction. As a molecule in the chain receives an electron, it is reduced; the molecule is oxidized, returning to its former state, as it releases the electron to the next member of the chain. Each transfer of electrons is catalyzed by a specific enzyme, and the energy released by some of the transfers is used to make ATP.
> In desulfovibrios, the last member of the chain passes the electron to sulfate.
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> "The evolution of electron-transport chains has had incalculable consequences. They are an indispensable part of the photosynthetic machinery [sic] of bacteria, algae and plants. Electron transport is always required from respiration whether of oxygen, sulfate, nitrate, or CO2. Oxygen respiration is the ATP-producing pathway in nearly all eukaryotes. Electron-transport chains are remarkably similar in the molecules that make them up – both the enzymes and the electron carriers themselves in organisms that superficially vastly differ."
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> Lynn Margulis and Michael Dolan. 2002. *Early Life: Evolution on the Precambrian Earth.* **2nd edition.** Jones and Bartlett Publishers. pp. 42-43.

In *Acquiring Genomes*, Lynn addressed a question that nagged me during my doctoral studies: how are we to characterize what, exactly, is doing natural selection? In this introductory passage of chapter 4, she stresses, like Lovelock, that Gaia theory is not only consistent with natural selection — counter to early criticisms by neo-Darwinians — but that natural selection is actually part of Gaia theory; the latter extends our understanding of the former. The chapter expands on this introduction.

"What then does the selecting in natural selection? Just as many modern evolutionists permit themselves an unscientific vagueness about the role of natural selection in evolution, they also remain vague about the identity of the natural selector. It is all too easy to wave one's arms and say 'the environment selects, the fittest survive.' What does 'fit' really mean? What parts of the environment select? How far does the environment extend? Questions like these tend to be answered only in generalizations or in an ad hoc manner, case by case. A staunch resistance to any systemic effort to identify the agent or agents of natural selection takes place.

"The simple but important assertion made in this chapter is that the natural selector is Gaia. Gaia, the biosphere [sic: includes the biosphere but is MUCH more], is best understood as the whole Earth's surface of interacting conditions and the biota, living matter, [atmosphere, oceans and lithosphere] naturally organized into ecosystems. 'Biota' or total biomass refers to flora, fauna, and microbiota taken together. Natural selection is one of the means by which Gaia, the self-regulating system, maintains itself as a dynamic but stable entity."

Lynn Margulis and Dorion Sagan. 2002. *Acquiring Genomes: A Theory of the Origins of Species,* Basic Books, p. 68.

Finally, in *Symbiotic Planet*, Lynn displayed her dislike of claims that we must "save the Earth", or of arguments by writers like Derrick Jensen who claim that we are "killing the Earth". Jensen is a popular writer among anarcho-primivists because of his assertion that we should actively – by what ever means necessary - end industrial civilization lest it will kill Earth. By citing this quote, I am neither supporting nor condemning Jensen's views about industrial civilization, only pointing out a flaw in his argument about humans being able to "kill" Gaia. The quote also illustrates another point about Lynn: she didn't mince words.

"The Gaia hypothesis is not, as many claim, that 'the Earth is a single organism.' Yet the Earth, in the biological sense, has a body sustained by complex physiological processes. Life is a planetary-level phenomenon and Earth's surface has been alive for at least 3,000 million years. To me, the human move to take responsibility for the living Earth is laughable – the rhetoric of the powerless. The planet takes care of us, not we of it. Our self-inflated moral imperative to guide a wayward Earth or heal our sick planet is evidence of our immense capacity for self-delusion. Rather, we need to protect us from ourselves… We need honesty. We need to be freed from our species-specific arrogance. No evidence exists that we are "chosen", the unique species for which all the others were made. Nor are we the most important one because we are so numerous, powerful, and dangerous. Our tenacious illusion of special dispensation belies our true status as upright mammalian weeds…. The planet is not human, nor does it belong to humans. No human culture, despite its inventiveness, can kill life on this planet, were it even to try. Less a single live entity than a huge set of interacting ecosystems, the Earth as Gaian regulatory physiology transcends all individual organisms. Humans are not the center of life, nor is any other single species. Humans are not even central to life. We are a recent, rapidly growing part of a single huge ecosystem at Earth's surface."

Margulis, Lynn, 1998, *Symbiotic Planet: A New Look at Evolution*, Basic Books. pp. 119-120.