

DYNAMIC "SYMBIONTS" LINKED OVER TWO CENTURIES: A TRIBUTE TO LYNN MARGULIS (1938–2011)

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Charles Darwin requested that his friend the botanist Joseph Hooker tell the great explorer/science thinker Alexander von Humboldt that the "whole course of my life" was determined by reading Humboldt's remarkable *Personal Narrative* (1852). Darwin was said to have carried Humboldt's writings everywhere, and he referred to him as "the greatest scientific traveler who ever lived." Indeed, one can say that Darwin's late-in-life expressions of the "network of life" reflected his foundation in Humboldt, arguably our first ecologist *per se*.

In my mind, Lynn Margulis, whether she realized it or not, was decidedly "Humboldtian." While he relentlessly and physically explored previously untouched areas of the globe, focusing particularly on tropical ecosystems, Margulis mentally explored those areas of biology where the mind had not dared travel. His perseverance and unparalleled resourcefulness led him to scale the highest mountain peaks known in the early 19th century. She conquered mountainous dogmatic science tradition and obstructive male chauvinism in providing a new realization of the dominance and impact of endosymbiosis. Humboldt constantly ignored established protocol by emphasizing the deep attributes of indigenous peoples and the need to respect cultures and races worldwide. Similarly, Margulis rebelled against convention as well and paved the way for a new emerging respect for Lamarck, Kozo-Polyansky, Vernadsky and others. Humboldt invented entire new disciplines such as biogeography and global ecology that allowed for new concepts of the merger of life and non-life forces, which are more relevant today than ever. She resurrected symbiogenesis, co-originated Gaian concepts, and poked holes in neo-Darwinian thinking, thereby initiating new paradigms of how we see the earth and ourselves. He stressed that living systems cannot be understood without a geological context and constantly saw the need to merge disciplines, while Margulis forged a similar synergy, always revealing the microbiogenic nature of much of the biosphere,

from limestone to oxygen proliferation. Humboldt put his mind in outer space, gazing back to the flora and fauna, the rocks and waters and thus promoting the notion that accessing the whole – the Cosmos – cannot be achieved solely through reductionist thinking. Margulis travelled always in inner space, the Microcosmos, and profoundly exposed the dominance and impact of microbes extending back nearly four billion years.

I am reminded of one of Lynn's lesser-known studies (Duval and Margulis, 1995), which demonstrates her often forgotten strong natural history sensibility. A local pond revealed the mind-boggling rare organism, *Ophrydium versatile*. One phase of this heterotrophic protoctist, the zooids, build startling semi-transparent gel-balls sometimes up to a half meter in diameter that roll and dance at the water surface. These arc-shaped zooids expand and contract, capturing detritus in the water, while their often elongated interior contains hundreds of algal cells, usually of the genera *Chlorella* or *Grasiella*. These endosymbiotic algae provide the high carbon



Lynn Margulis and Douglas Zook (2009) in classroom/lab, having a lengthy video interview/discussion.

flux needed to build these gelatinous aquaspheres. The gel not only houses and protects the zooids but supports about forty "selected" microbes living as a community within. This unique microbially based mass relies on endosymbiosis to ultimately express a kind of mini biosphere of the earth – an ecology within a gel-mass. It is as if the ideas of both Humboldt and Margulis merged into this spectacular mega-chimeric expression – especially as the analogy of the *Ophrydium* with our biosphere is unavoidable.

While Humboldt has been and remains a special guide and beacon to me, he nevertheless has only been alive for me through the pages of a book and through his wonderful geological and botanical drawings. Lynn, on the other hand, was a living flesh-and-blood mentor and friend for over three decades. This began in 1978 on the first day I attended her Evolution course, when I mistakenly believed I would go on a journey into how primates emerged and developed. Instead, the biological reality of our living in a microbial world spurred waves of new ideas, rethinking, and realizations that have only grown more profound over the years. It was not long before I became acutely aware of the dual (perhaps even triple) ancestry of each of our cells (with the exception of red blood cells) and the triple ancestry of each of the plant and autotrophic protocist cells. It was also clear that eukaryotic "flagella" should really be called "undulopodia" and that this was not trivial, that the early gene sequencing of biochemists Schwartz and Dayhoff (1978) provided an open-and-shut case for the symbiotic origin of eukaryotes, as Lynn pronounced in one memorable class session, that biological sex has linkages to symbiotic processes and microbial cannibalism, that the prevailing view of just two basic kingdoms rather than five or more was a myth; that many bacteria are not single-celled, and more, seemingly and delightfully *ad infinitum*.

Within a couple years after the course, Lynn and I found ourselves immersed in grand notions of a "micro-museum," a unique active facility that would help the public and especially teachers and their schoolchildren discover the beauty and diversity of the microbial world. While this particular vision did not come to fruition with us, similar microbial museums such as the Micrarium in Buxton, England and the New York Hall of Science in Queens, New York did, influenced by the thinking and microbially-based writings of Lynn. However, our "museum" idea did morph into the International Microcosmos project (Zook, 1994) which eventually led to nearly 400 teacher workshops on microbial life throughout the U.S.A. and in six other nations, a

few in which Lynn directly participated with her famed and inspiring gusto.

Lynn's willingness and commitment to teach and guide even on a pre-college level further exemplified the breadth of her wingspan, her willingness to migrate and nurture near, far and in between. This realization led me back to Humboldt, who nearly two hundred years ago realized that we could make better sense of the earth and its systems by uniting geography, climate, and living things. Humboldt thus envisaged the now commonly measured "isopleths" – comparative lines of air pressure, temperature, or other data monitored globally. Thus, Humboldtian views of the earth began to be visualized as massive webs, with similar features connected as contours around the globe, a forerunner to our global measuring concepts today. Lynn's expansive thinking and insights fit this Humboldtian expression, for her ability to build many evidence-based connections across all scales and disciplines – including educating children about the earth – was profound.

Neither Lynn nor Alex would have appreciated these past tenses. Their ideas, risk-taking, findings, principles, brilliance and energy inspire us all. However, I am even more fortunate than Darwin, for I move forward now embracing the wisdom of both Alexander von Humboldt and Lynn Margulis.

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Opening keynote presentation at the 7th International Symbiosis Congress (Kraków, Poland, July 2012), which was dedicated to the memory of Lynn Margulis, outstanding scientist. It is particularly appropriate that this tribute appears in this journal based in Cracow, for shortly before her passing, she told me how very much she looked forward to coming to the Jagiellonian University in Cracow, "the great city of Copernicus", as the invited keynote speaker to this Congress. DZ