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Some Ecological and Human Lessons of Biosphere 2

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ABSTRACT

The Biosphere 2 project, a 1.2 hectare materially-closed mini-biosphere that supported teams of biospherian crews from 1991–1994 provides a host of ecological and human-biosphere lessons relevant to our global biospheric challenges. Because of its high visibility through worldwide media coverage, the project advanced public understanding of what a biosphere is and the roles that humans can constructively play in keeping ecosystems and atmosphere healthy. The present paper reviews the fairly recent scientific understanding of our global biosphere and some of the intriguing results from Biosphere 2. It also examines some of the reasons that Biosphere 2 aroused controversy because of narrow definitions and expectations of how science is to be conducted. The cooperation between engineers and ecologists and the requirement to design a technosphere for Biosphere 2 that supported the life inside without harming it has enormous relevance to what is required in our global home. There was an unexpected and profound connection that the 'biospherian' crew inside Biosphere 2 felt to their living biosphere. Biosphere 2 also demonstrated new kinds of roles that can be played by people aware of a biosphere as their life support system.

KEYWORDS

Biosphere 2; technosphere; biosphere; human-biosphere paradigm; self-organization; mini biosphere; biomes; biospherians; reductionist/holistic; scientific taboos

INTRODUCTION

Vladimir Vernadsky is credited with forging our modern understanding of the biosphere, a term coined by Eduard Suess in 1875. Vernadsky, who also founded biogeochemistry, came to see that the biosphere has transformed the Earth's surface by its processes over billions of years. Life is not simply a passenger on the Earth – but has fundamentally altered it. Earth's life and the planet itself are inextricably and extensively coupled in their processes and evolution. Vernadsky's 1926 book, *The Biosphere*, presented a vision of the force of life, ever including more matter in biotic circulation as it evolved and spread (Vernadsky, 1998).

The great Russian scientist was also a visionary in seeing that man's enormous ability to move matter had made our species a virtual geological force. Working in Paris in the 1920s, he and a few other thinkers foresaw the necessity of a 'noosphere'(from the Greek, meaning a sphere of intelligence) to harmoniously reconcile two powerful vectors, the biosphere and the 'technosphere'. The technosphere encompasses all of humanity's technologies including agriculture/ranching, industry and the built environment (Trubetskova, 2004). An influential book on the problems of realigning the technosphere to not harm the biosphere by the environmentalist Barry Commoner was entitled 'Making Peace with the Planet' (Commoner, 1990).

In more recent decades, there has been a call to designate a new geological era, the Anthropocene, in recognition of the unprecedented role of humans in changing land use, resource consumption and altering of basic geochemical cycles (e.g., Schwagerl, 2014; Davies, 2016).

This modern understanding of the biosphere and the critical need to address human impacts on its functioning comes amidst a growing alienation and disconnect of people from the ecological realities of their lives.

1. BIOSPHERE 2: REAL-TIME AND HIGH PROFILE ECOLOGICAL SCIENCE

The design and construction of Biosphere 2, including associated research, took place between 1984 and 1991. There were several purposes of the project. First, to create a new kind of laboratory where the interactions of areas modelled on the Earth's biomes, an intensive agricultural system and all the engineering needed to support eight people could be studied. Secondly, to begin learning how to create miniaturized biospheric systems for eventual use in long-term space habitation. Next, to develop innovative eco-technologies to ensure full recycling and successful operation of the materially-closed system. The fourth, responding to global excitement and interest in the closure experiments, to conduct educational programs for students at all levels and the public on how ecology and our biosphere functions (Nelson, 2018; Nelson et al, 2003; Nelson et al, 1993a; Allen, 1991).

The project gained the support of the Russians who were leaders in closed ecological system research and in bioregenerative space life support systems. They saw that Biosphere 2 could take the field to the next level, a Vernadskian biospheric one. To create energetically and informationally open but virtually materially-closed systems would allow precise monitoring of the system and the potential to track subtle and small changes over time (Dempster, 2009; Morowitz et al, 2005).

There were great ecological and engineering unknowns. Could viable ecologies including food webs be created in biomes that covered just 0.2 hectares (1/2 acre) ranging from tropical rainforest, savannah, coastal desert, mangrove/marsh and coral reef ocean systems? Ecological designers decided to 'species-pack', including far more species than might be expected to persist, in the hopes of having redundancy for important ecological niches. The crew intervened to 'defend' biodiversity, functioning as surrogate keystone predators controlling invasive plants and cutting savannah grasses since we lacked grazing animals. The coral reef system survived despite the change to temperate seasons but required chemical buffering to limit acidification of its waters and removal of algae. The Biosphere 2 four million litre ocean was later used to provide important data on how coral reefs will fare with global warming and ocean acidification (Langdon et al., 2000; 2003). The coastal desert changed its character, self-organizing and adapting to a more chaparral domination than the original cacti/succulents. But these were the reasons for building Biosphere 2 – since it's clear that there is so much that is unknown about basic ecological and biospheric processes (Nelson, 2018; Nelson et al., 2013).

I like to describe Biosphere 2 as the greatest experiment in ecological self-organization ever undertaken. It was also profoundly what John Allen, Biosphere 2's inventor, called 'The Human Experiment'. It was no surprise to the people who designed and lived inside Biosphere 2 that there would be completely unexpected occurrences during initial experiments, such as the at first mysterious decline in atmospheric oxygen. The good news was that despite Biosphere 2's size and complexity, that mystery could be solved with creative use of carbon isotope tracking and an out-of-the-box suggestion to see if absorption of CO_2 from Biosphere 2's elevated atmospheric levels in untreated concrete was the sink for much of the oxygen (Severinghaus et al, 1994).

For more of the publications on Biosphere 2, see Marino and Odum (1999) who edited a collection of nearly two dozen papers for Ecological Engineering (later published by Elsevier) and online at http://www.biospherics.org/publications/1984-2003/.

2. OBSTACLES: SCIENCE TOTEMS AND TABOOS

Amongst the obstacles to research relevant to a new paradigm of the human-biosphere relationship are those that arise from a too narrow definition of science.

Some of the controversies that Biosphere 2 ignited stemmed from the perception of the core creative team of the project as 'outsiders'. This was despite the many high-level scientists and institutions which contributed to Biosphere 2's design and research studies.

Biosphere 2 was intended as a quiet research facility. But its mix of an optimistic premise, humans and a mini biosphere could be engineered and managed to work together, and the excitement of real-time science somehow touched people around the world. Biosphere 2's architects, determined to make human's first attempt at a long-term biospherics laboratory a beautiful symbol, used traditional forms (stepped pyramids, Babylonian barrel vaults) along with modern forms like spaceframe and geodesic domes to create a stunning facility. From being a relatively obscure word, 'biosphere' was suddenly reaching an immense number of people. Biosphere 2 was a compressed laboratory for studying the processes of our global biosphere, and it was readily comprehended as a model biosphere (Nelson, 2018).

Rebecca Reider had studied Biosphere 2 for a history of science thesis at Harvard University. The book she later published explored some of the many reasons Biosphere 2 aroused controversy. She delineated four ways that Biosphere 2 deviated from popular expectations of how science was conducted.

> '"Science" could be performed only by official scientists, only the right high priests could interpret nature for everyone else…."Science" was separate from art (and the thinking mind was separate from the emotional heart)… "Science" required some neat intellectual boundary between humans and nature; it did not necessarily involve humans learning to live with the world around them. Finally, "science" must follow a specific method: think up a hypothesis, test it and get some numbers to prove you were right (Reider, 2009).

These narrow definitions of science which exclude 'learning to live with the world around them' impede the contributions that science can make a transition to a healthier relationship with our global biosphere including the badly needed rethinking and redesign of many current elements of our technosphere.

That science must follow a specific, hypothesis-driven, format is a reflection of the current emphasis on and dominance of analytic, small-scale science. While all scales of science are worthwhile, the bulk of research funds supports analytic science, not systems level science which could address pressing ecological issues. Making matters worse is occasional hostility and incomprehension of some 'reductionists' towards other approaches to science (Odum, 1996).

Finally, the exclusion of the heart and art from science leads to an even greater 'scientific apartheid' than Lovelock (1979) had in mind in assessing why there is so little multi-disciplinary research and projects despite decades of calls for their implementation. Most scientists are well aware of the passions that motivate their work. Emotions are key tools in motivating us to do science that can be relevant to our global issues as well as helping make us whole human beings.

3. REDESIGNING THE TECHNOSPHERE

Among the unusual collaborations that enabled Biosphere 2 to function as well as it did was the close working together of engineers and ecologists. The ecologists had to learn the language of engineers to translate their designs for species-rich, landscape diverse mini-biomes into what was needed to technically support these systems. Conversely, the engineers had to learn a new principle: the technosphere's priority was to support the life inside the facility. No technology or material could be used if its by-products were toxic to living organisms (Nelson, 2018; Alling and Nelson, 1993).

Many of the creative team behind Biosphere 2 had previously worked with the Institute of Ecotechnics. A diverse group including myself started I.E. in 1973 and our goal was to advance the harmonization of eco- and techno-. We helped create and managed the demonstration field projects around the world in challenging biomes, where conventional solutions do not work (Allen et al., 1984). Our aim was to achieve top line improvement of the ecology along with viable economics (bottom line) so the projects could be self-sustaining. In Biosphere 2, the objective of learning how to make a world where humans, technology, farming co-existed with rainforest, savannah, desert, mangrove/marsh and coral ocean made it an excellent laboratory for developing ecotechnics. Indeed, several of the innovative eco-technologies of the project included regenerative farming, ecological methods of trace gas control and wastewater recycling (Nelson and Bohn, 2011; Nelson and Wolverton, 2011, Nelson et al., 1993b).

4. CONNECTED: THE BIOSPHERIAN EXPERIENCE

One of the unanticipated results of the creation of closed ecological systems supporting humans were their feelings of deep connectedness with their living world. During the Biosphere 2 project, this was first observed with human experiments in the Biosphere 2 Test Module, a 480 m^3 facility with a footprint 6.1 m x 6.1 m. Packed with plants from the biomes that would be included in Biosphere 2, it included a constructed wetland for treating human waste and food crops (Alling et al, 1993). Its first test subject, John P. Allen, noted during his three-day closure experiment in 1988:

> 'Already a strange partnership has started building between my body and the plants. I find my fingers stroking, feeling the soft rubbery texture of the spider plant, knowing it's picking up outgassing products…Notice my attention turning more and more to the condition of the plants…I've always had the sense of plants being alive, responsive, even a living symbol. But now they're necessary…and since they're necessary, I look out for them' (Allen, 1991).

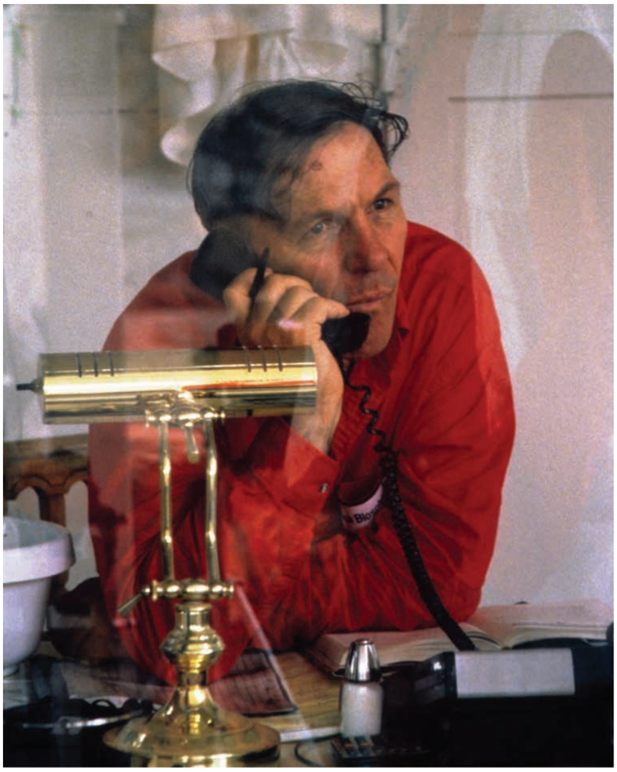

Figure 1. John P. Allen in the small habitat room, with kitchen, bathroom and bed, inside the Biosphere 2 Test Module during his three day experimental closure in 1988.

Later, after I spent 24 hours in the Test Module, the depth and wonder of the experience convinced me to begin training as a 'biospherian' crew candidate for the planned two-year closure experiment in Biosphere 2. In such a small facility, the metabolic connection between you and the rest of the life inside hits you almost immediately. Even while inside the small human apartment of the facility with no sight of the plants, you're aware that you are dependent on all that life for your health and well-being. You carry out your responsibilities to maintain equipment, ensure irrigation is occurring, fans and pumps are working, with a mindfulness that begins with bodily knowledge of your interdependence (Nelson, 2018).

Similar experiences during the 1991–1993 closure experiment in Biosphere 2 were felt by all eight of the biospherian crew. It did not manifest quite as quickly because the 1.2 hectare facility is vastly larger than the Test Module (Figure 2). But it nevertheless was small enough that one's linkages were clearly perceived. What was remarkable was that the awareness was not just a cerebral, intellectual knowing, but was far deeper. All the crew would have described themselves pre-closure as committed environmentalists, deeply concerned about ecology and wanting to contribute to keeping our global biosphere healthy. But the connection experienced in Biosphere 2 was more organic, rooted in a visceral awareness, a cellular understanding that one's health is synonymous with the health of the life inside this mini world.

In a small closed system, though the same nutrient and biogeochemical cycles are operating like in Earth's biosphere, the concentration of life and smallness of buffers (atmosphere, ocean, water volume) results in speeding up of atmospheric fluctuations. For example, in Biosphere 2 atmospheric CO_2 could vary by 600–700 ppm per day and atmospheric residence time was measured in hours not years since the whole system was in sunlight during the day, and respiration dominated during dark hours (Nelson and Dempster, 1996; Nelson et al., 1994) (Figure 3). Water cycles were also accelerated by orders of magnitude (Table 1 and Table 2).

The biospherian crew often referred to the plants inside our world as our 'third lung'. Amongst the chief challenges we faced was maintaining a healthy atmosphere; so we became hands-on atmospheric managers to limit the rise of CO_2 during low-light seasons. This included pruning vegetation that could quickly regrow and storing (sequestering) the cut biomass, turning off compost and worm bed operations, and planting to capture more sunfall within the system. The sense that the plants were our 'green allies' reinforced our gratitude

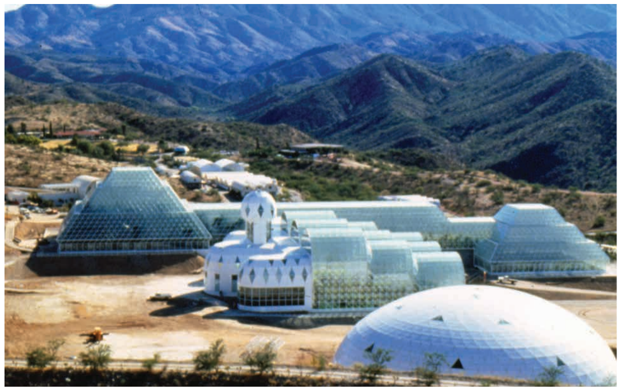

Figure 2. The Biosphere 2 facility, Oracle, Arizona. In foreground is the geodesic dome covering one of the variable volume chambers (lungs), the opaque structure is the Human Habitat, the barrel-vaulted space frame structure houses the intensive agriculture biome. At the rear are the 'wilderness' biomes, from rainforest on the left in stepped ziggurat structure, savannah/ocean, mangrove/marsh and desert to the right

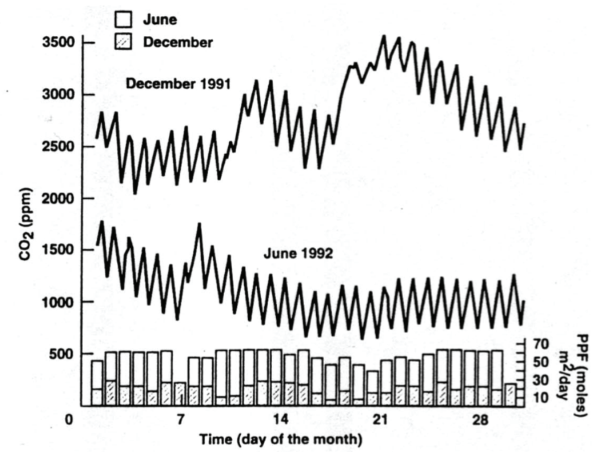

Figure 3. Graphs showing the high correlation between atmospheric CO_2 levels and summer/winter incident light inside Biosphere 2. Bar graph at bottom shows December 1991 sunlight vs. June 1992. During this winter period, CO_2 varied from 2100 ppm to 3700 ppm, while in the summer month, the concentrations fluctuated from 800 ppm to 1700 ppm (Nelson, 2018).

Table 1. Earth's biosphere carbon ratios of biomass, soil and atmosphere compared to Biosphere 2. This results in dramatically different carbon cycling, atmospheric residence (after Nelson et al., 2003, data from Schlesinger, 1991; Nelson et al., 1993a; Bolin and Cook, 1983)

	Earth	Biosphere 2
Ratio of biomass C: atmospheric C	1:1 (at 350 ppm CO_2)	100:1 (at 1500 ppm CO_2)
Ratio of soil C: atmospheric C	2:1	5000:1
Estimated carbon cycling time (residence in atmosphere)	3 years	1-4 days

Table 2. Water fluxes and residence times in Biosphere 2 and the Laboratory Biosphere compared to Earth's biosphere (from Dempster, 1993; Dempster, 1994; Tubiello et al., 1999, Nelson et al., 2009)

Reservoir	Earth residence time	Biosphere 2 estimated residence time	Acceleration of cycle compared to Earth
Atmosphere	9 days	~4 hours	50-200 times
Ocean/Marsh	3000–3200 years	~1200 days (3.2 years)	1000 times
Soil water	30–60 days	~60 days	similar

to them for helping purify water, cleanse air and from the food crops supply our meals (Nelson, 2018).

The variety of roles that we had to carry out also deepened our connectedness. These included farming in a regenerative system, which used no toxic chemicals and recycled nutrients and water, maintaining technical equipment, intervening when necessary to defend biodiversity, monitoring and collecting data, and conducting research in association with outside scientists. Most of the crew celebrated our mini-world with poems, paintings, music, documentary films and in writing. We even convened two 'interbiospheric arts festivals' to share with outside artists and musicians.

Though, like almost all people in ICE (isolated, confined environments), there were significant issues with group tensions during the two year experiment; there was never any subconscious sabotage of other people's work or research nor of Biosphere 2 itself. This facility was so palpably our life support system that it was unthinkable that anyone would damage it. Realizing that it was our life boat led to a high degree of mindfulness about any action we considered undertaking. The beauty of the world we were living in and our physical, emotional bonding with it were sources of great satisfaction and helped hold the crew together despite an outside power struggle and internal frictions (Nelson, 2018; Nelson et al., 2015) (Figure 4).

Figure 4. Biospherian crew for 1991–1993 closure experiment in Biosphere 2 in front of a feast day table of food grown in our intensive agricultural biome. The farm used no toxic chemicals, irrigation water was recycled, and nutrients were returned through compost and a constructed wetland wastewater treatment system (Nelson, 2018). The farm was one of the most productive 0.2 hectares (half acre) in the world (Silverstone and Nelson, 1996). The low-calorie, high nutrition biospherian diet was also intensively studied for its health impacts (Walford et al., 1996).

5. CONCLUSIONS

Biosphere 2 continues to function as an important scientific facility, now owned and managed by the University of Arizona. It has been changed from a materially-closed system supporting people to one where ecological systems can be studied and experimentally manipulated.

But its early years of operation as a mini biosphere make it a landmark and pioneering endeavor. Now that the early controversies and media notoriety have faded, the detailed record of how diverse ecological systems were designed, created and adapted to unique environmental conditions is unprecedented (e.g., Leigh, 1998; Finn, 1999).

Similarly, there is much that can be learned from the human experience of being so connected, responsible for and dependent on a living world for one's health that is applicable to our global population struggling to come to terms with how to live with Earth's biosphere.

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