Biosphere 2 as a Case Study in Global Change:  
Educational Lessons Learned

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Abstract

The Biosphere 2 project has evolved through changes in institutional management. Problems in monitoring and managing the synthetic biomes are described. The lessons are relevant for sustainable inhabitation of complex living systems. The way students learn about Biosphere 2 is presented, followed by examples of how the lessons have been incorporated into other courses offered by Columbia University.

1. Introduction

This presentation is based on my experience with the Biosphere 2 project and its derivative educational programs. I am reporting lessons learned and shared by many dedicated people.

The Biosphere 2 project was a microcosm of problems posed by our civilization’s accelerating influence upon our planetary biosphere. They included unstable atmospheric chemistry, rapid climate change, unexpected ecological dynamics, and pervasive human disturbance of landscapes. Two fundamental problems apply equally to Biosphere 2 and sustainable development of our planetary biosphere: 1) Knowledge about how to understand and monitor complex living systems is inadequate, 2) There is no sustained dialogue to reach a consensus about what is true, good or even valuable in the living world beyond our culture. This leads to confusion in management ethics, goals and practices (Allenby 1999).

2. The Biosphere 2 Project

Biosphere 2 was the focus of a learning enterprise. Inspired by the Gaia Hypothesis (Lovelock 1988), the goal was to create small biospheres that replicate the functions of our planetary biosphere. A primary criterion for success was sustained material

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recycling that could support human inhabitants of closed systems (Allen/Nelson 1999).

The project was managed by a private corporation, Space Biospheres Ventures, which intended to profit from the sale of expertise and relevant technologies. Biosphere 2 was designed to have one atmosphere shared by different kinds of biomes. “Wilderness biomes” were to perform ecological functions, the most important being the regulation of atmospheric chemistry. The biomes were to simulate the gradient from equatorial rainforest to subtropical deserts, compressed into 145 m, with a coral reef and mangrove swamp included (Marino/Odum 1999, Leigh et al. 1999, Atkinson et al. 1999, Finn et al. 1999). As a consultant, I supervised the design and construction of the desert biome, and assisted with the savanna-thornscrub biome as well.

There were two closed missions. The first, with eight humans, lasted two years. Atmospheric carbon dioxide levels reached 4200 ppmv, and oxygen dropped to 14.2% (Engel/Odum 1999, Allen/Nelson 1999). To promote carbon sequestration rainfall was increased in the desert biome. The vegetation responded rapidly, and by the end of the first mission, the open desertscrub had become a dense grassy chaparral. The utility of a desert biome for managing a carbon-enriched atmosphere was questioned; and before the second closed mission the conversion of the desert biome to Mediterranean woodland vegetation was begun.

The corporate context constrained information management. After the initial concentration of consulting expertise, information flow was restricted ‘to protect the investor.’ Care had to be taken not to compromise potential trade secrets and patents by inadvertent presentation in the public domain. There was also a need to project corporate infallibility, in order to promote investor confidence. My role as a scientific consultant to private enterprise required balancing client confidentiality and loyalty with my professional integrity.

Dissension in corporate management led to the dismissal of most senior management on 1 April 1994. The second closed mission with seven people was ended after seven months. Interim management objectives were to improve operation efficiency, trim costs drastically, and seek new options for income. I became the manager of the terrestrial biomes in Biosphere 2, and I started restoration of the desert biome.

In January 1996 Columbia University assumed management responsibility of Biosphere 2. Biosphere 2 Center was created as a component of Columbia’s Earth Institute. Operations were initially subsidized by the site owner, but the campus was to become self-supporting through a combination of research grants, tuition and tourism.

When a group of nationally recognized ecologists met to propose the best research uses for the Biosphere 2 biomes, I was told that although the diversity of organisms and habitats inside the structure was interesting, it was scientifically useless, because no replicated experiments were possible. The original research plan had been to assemble the system, describe its initial state as well as possible, observe
subsequent dynamics, learn how to manage a biosphere, and discover fundamental research questions necessary to develop a science of biospherics (Allen/Nelson 1999). The facility was to model Earth’s biosphere with many biomes sharing one atmosphere, and material closure was essential. For many scientists introduced by Columbia University, the facility was most attractive as a platform for controlled experiments, and each biome had to be isolated. In the initial research paradigm, understanding dynamics of atmospheric carbon dioxide concentration was a critical priority. In contrast if the facility were to be used for global change research, carbon dioxide levels must be carefully controlled. Regulating atmospheric chemistry is easiest when air flows through the biome from outside. Changing the structure from one epistemological mode to another required a substantial investment.

I found it difficult to sustain attention to the countless details and relationships necessary to manage diverse biomes. The sensor array provided a stream of data, but there was little time for continuing analysis. Reliable monitoring required calibration and repair of sensors, biomass measurements, and population censuses. As resources dwindled, these activities were curtailed. One species of ant, *Paratrechina longicornis*, became so abundant that it restructured the entire terrestrial food web (Wetterer et al. 1999), but resources were inadequate to fully document the process. Determining whether a biome was “healthy” proved neither simple nor straightforward. The continuing challenge was to discover the most cost-effective methods to monitor and model dynamics; this cannot be done working alone.

The preservation of data archives through successive cohorts of administrators and researchers was not consistent, because each new group seldom valued the research methods and data gathered by predecessors. Changes in information technology complicated retrieval of data, but the fundamental problem was a lack of motivation for sustained archiving.

“One of the most important objective results of the Biosphere 2 experiment … was to produce ‘Noosphere 1’…” (Allen/Nelson 1999, 20). Each biome was heavily influenced by mental models of its designers and managers; hence Biosphere 2 may predict what Earth’s biomes become as cultural influences supersede biological processes.

3. Educational Response to Biosphere 2

One goal of Columbia University was to create a center for educational innovation, where students could be trained for careers that would support sustainable inhabitation of Earth. In student surveys the most valued aspects of our educational programs have been the student community, the field experiences, and easy access to faculty and teaching staff. Our curricula share many features with other intensive, immersion, multidisciplinary programs, for example Evergreen College and the Audubon
Expedition Institute. Two unique aspects are presented here: how we teach Biosphere 2, and how we have incorporated Biosphere 2 lessons into our programs.

3.1 How Biosphere 2 is taught

Biosphere 2 can bewilder students, because there are so many ways to think about what could be learned and what should be understood. During their first visit I encourage students to embrace confusion, because it may lead to new insights. In groups, they explore the biomes of Biosphere 2 and are introduced to the questions that arose during its design and operation. Their assignment is to create a presentation that answers a primary question: either “How should Biosphere 2 be used to create knowledge?”, or “How should Biosphere 2 be used to disseminate knowledge?”

To show how to cope with ecological complexity, I organize questions into four research paradigms: biome, community, ecosystem, and noosphere. The first three were developed by Allen and Hoekstra (1992). Their analysis of ecological complexity using hierarchy theory and contrasting paradigms provided valuable insights into Biosphere 2; thus I introduce students to their concepts. The paradigms can be related to synthesize a broader perspective.

Biomes are defined by a vegetation structure associated with a particular regime of climate and disturbance. The phenomena of interest within the biome paradigm are vegetation structure and the context of temperature, soil moisture, disturbance, etc. Examples of relevant questions follow:

- What physical conditions best support the functioning and evolution of each biome?
- How do biomes maintain separate identities in such close proximity?

The community paradigm focuses on biotic interactions and their effects on community structure. Key observations include species composition, food web relationships, inferred competition, and pollination. Closure made Biosphere 2 into a ‘hyper-island’ and isolated its community. Design and management of community architecture involved these questions:

- Within the limited space of Biosphere 2, is it better to have larger populations of a few species, or smaller populations of more species? More genetic diversity within a population increases its evolutionary potential. More species diversity may increase the stability or resilience of food webs.
- Which will produce the most resilient community: overpacking species and letting extinction reduce the diversity to a sustainable level, or assembling the community a few species at a time?
- Should communities be allowed to progressively diverge in isolation from their prototypes, or should there be periodic introductions of species to promote conformity with a particular community outside?
How much should human managers intervene as “keystone predators” in order to prevent one species from becoming too dominant, or to prevent extinction? The more humans meddle, the more the community resembles a garden.

The emphasis on species and their interactions differs from research in the ecosystem paradigm, where the flows and compartments of substances and energy are of greater interest. Within the ecosystem paradigm, a species population is perceived only as a compartment within a system of circulation, and many species may be lumped together as a single compartment such as “trees”.

The ecosystem paradigm involves links among the biota and their physical surroundings, and the mass balance within the whole system. Linkage occurs through the flow of energy, carbon, water, etc. through the system. Ecological functions are studied within this paradigm. Material closure defined Biosphere 2 as a single ecosystem with several biomes. These ecosystem questions arose during the design and management of Biosphere 2:
Should several biomes be grouped into a single ecosystem, or should each biome be physically isolated as a discrete ecosystem?
How does the chemistry of the atmosphere and water influence ecosystem processes?
How can ecosystem processes be used to predict and control atmospheric and water chemistry?

The noosphere paradigm focuses on the human role (Samson & Pitt 1999). One aspect is how each Biosphere 2 biome creates value commensurate with the cost of its construction and maintenance. This involves a consensus about what is valuable or “good” for society. Another noospheric topic is how each biome may contribute to psychological health (Roszak et al. 1995). The first aspect involves economics; the second, aesthetics. Biomes and organisms that were appreciated by the crew were tended; those less popular were neglected or destroyed. The noosphere paradigm involves comparing mental models and clarifying how people evaluate their living environment.

3.2 Incorporation of Biosphere 2 lessons into education

As a biome manager I found conventional ideas about command-and-control management inadequate. My training in science was vital, but effective stewardship required more skills. Scientists are not always effective managers (Holling 1995). Understanding and managing a complex living system requires a community of diverse expertise and different learning styles. How can this be learned and taught?

I found promising models in the concepts of learning organizations (Senge et al. 1994) and adaptive management (Holling 1995). Both the learning cycle described by Ross et al. (1995) and the cycles of institutional destruction and renewal described by Gunderson et al. (1994) show the need for different thinking styles and personalities to move through successive stages of learning. The process of a dia-
Dialogue described by Isaacs (1994) is especially appropriate. “During the dialogue process, people learn how to think together – not just in the sense of analyzing a shared problem or creating new pieces of shared knowledge, but in the sense of occupying a collective sensibility, in which the thoughts, emotions, and resulting actions belong not to one individual, but to all of them together” (Isaacs 1994, 358). A dialogue could sustain a learning organization. What if a dialogue involved ecological communities? I realized that my task was not to control the living systems, but instead to facilitate a continuing negotiation that allowed as many species as possible to coexist, thereby sustaining the resilience of the system and its potential for evolutionary innovation. I believe that a sustainable relationship between a human society and the landscape it inhabits could be derived from a dialogue, hence this aphorism: the future of our Earth depends upon the quality of our conversations.

To practice effective communication, we require group projects. Many students have little experience with teamwork, consequently emotional and communication difficulties often occur. Thus concepts of learning cycles, learning style, rapport, conflict resolution, and dialogue are introduced. In addition, we emphasize integration at several levels, not only among different academic disciplines, but also among different ways of knowing and multiple intelligences (Gardner 1999), which reinforce the importance of diversity in learning communities.

Our field trips are seldom rigorous. Our goal is to demonstrate that students with no previous experience can learn how to be both physically and conceptually comfortable in field situations. Peer instruction and role models accelerate this process. Once students begin learning from each other, our objective is usually accomplished. Field trips promote the formation of a student community and familiarity with the instructors, which are much appreciated. The importance of direct experience is shown in this excerpt from a student’s field notebook: “…the desire to squash every bug that comes near me, and to jump back from every mouse and rat…has dissipated into an interest to learn about the creatures around me” (Jon Bent, 14 July 2002). Increased comfort level created a context for developing naturalist skills.

During the summer of 2002 Ms. Jenée Rowe, Mr. Jacob Brenner and I taught a new six-week course, Deserts of the Southwest. We created a more intensive field experience that could promote greater appreciation of deserts. To motivate individual and group learning in tandem, the students were graded on individual field notebooks and on their contribution to a final group composition. Our intent was to help students discover something that they were excited to learn, connect their chosen topic with a wider context of knowledge, and convey their findings and enthusiasm to a wider audience. The duration and rigor of trips increased progressively to allow adaptation to hot weather and remote locations. Basic safety skills, responsible camping techniques, and literary descriptions of deserts were introduced during the first trip, which started at relatively cool high elevations and ended in a mid-elevation desert. The following week was spent on campus learning basic concepts of microclimate and soil profile description, and planning the group composition.
We included sessions of painting to develop color perception. During the second trip to the northern Chihuahuan Desert, procedures for describing vegetation and basic photography skills were taught. After a brief interlude on campus, a two-week trip to Baja California allowed the comparison of desert communities along the Pacific coast from the edge of coastal sage scrub in the north to the most arid central part of the peninsula. Three days were spent in an oasis town followed by a brief excursion to the warmer coast of the Gulf of California. Each student was encouraged to pursue a topic of interest; for one it was lizards, for another, how people lived. All helped with the vegetation and soil profile descriptions, and they became aware of the variety of desert communities and the relationships among topography, soil, and plants. Prose, images, and quantitative data were organized on a laptop computer in the field, so that when they returned to campus, the students could rapidly assemble their final composition. The curriculum was ambitious, and not all objectives were fully achieved. Even so, students learned about desert communities, the conditions that create them, how to function in the field, and how to organize and present information about places. In the process, we formed a learning community.

In a time of proliferating information technologies, there is accelerating competition for human attention. Only those learning communities that access deeper levels of personal meaning and emotion can persist long enough for a genuine dialogue to emerge. I believe that sustainable development depends upon processing information through many connected dialogues. It is not enough to simply inform, the learning process must also enchant.

Bibliography


