BIOSPHERICS: A NEW SCIENCE OR SIMPLY A TEACHING EXERCISE?

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INTRODUCTION

Several years ago, in a class on “Biology of Changing Human Environments”, an undergraduate Josh Ness had led a discussion on Biosphere 2, the project in Arizona that isolated humans for several years in an enclosed artificial ecosystem to study whether such a system could be self-sustainable. This project received the obvious criticism that if its goal was scientific insight (which is arguable), then it was going about it the wrong way by generating a complex experimental system with no replication and no controls (or alternative treatments).

This naturally led to the question of how one might do it ‘properly’. Clearly the study of self-sustaining systems would require elements of simplification and replication. I sensed that very few attempts had ever been made to construct self-sustaining ecosystems, and that certainly the principles for their construction were known only at an anecdotal level at best (e.g. producer, consumer, energy source, recycling, species diversity etc.). Nor had I ever seen any discussion of whether such biospheres might engender genetic problems due to limited population sizes, inbreeding, or evolutionary change in the component species.

When I met with a new class the following year, I asked them if they wanted to focus on this one topic for the whole semester. I described the amazing potential of biospheres. We could make our own, we could keep them after college, we could even give them to our grandchildren. Would they gain value like rare works of art? Inside these spheres, would new species evolve? In a million (or billion) years might there be intelligent little organisms sending rockets up against the glass, trying to get out, trying to enter our universe from their universe? Perhaps I was too emotional, because the class unanimously chose to do take on the biosphere project!

What follows is an account of that project and what the students did, written by the students themselves (with a lot of peer review by them, and some by me). We decided that the class should split up into several groups to study different aspects of this discipline. Some would not even do science directly but would study the history of self-sustaining systems and their social context. Others would see if we could patent our biospheres and, if successful, start a company to produce them. One student was keen to review the literature, while others wanted to get into the lab. Two other brave souls decided that mathematically modeling biospheres might provide some insights, and so this became their designated task.

What follows is each of the student’s own accounts of their contribution to the class project.

Early History of the Biosphere Concept

Matt Alexander

I decided to research the history of the biosphere concept because it seemed like the field was beginning to gain recognition. In reviewing the literature, I found that the term "biosphere" was coined by an Austrian geologist named Eduard Suess. Suess published a book in 1875 on the genesis of mountains entitled *Die Entstehung der Alpen* in which he introduced the term "biosphere," although he failed to define it. Vladimir Vernadsky in the 1920's, reintroduced Suess' concept of the biosphere, but this time defining and explaining his ideas. He defined the biosphere as the area of earth inhabited by life used this definition to explain the interaction of the organisms within it. Vernadsky incorporated complex ideas such as biotic/abiotic interaction and the evolution of organisms over time. I was surprised that the biosphere concept had been developed so early in history. Although the concepts originated in the 1920's, experimentation with self-sustaining ecosystems did not begin until the early l960's. I wondered why the gap exists between the origins of the biosphere concept and the first experimentation. In other fields, such as evolution, the origins of the concept did not lead to rapid experimentation. Darwin first fully theorized evolution in the 1830s, but the first true experimentation in evolution did not begin for many years. I think both fields may have initially been considered on the margins of science and unworthy of scientific study. But over time the fields gained recognition and scientific validity.

In researching the history of the biosphere concept, I found that there is a lot of information on the web, but most of it commercial, trying to sell biospheres rather than provide basic information. Initially, this concerned me. Were we dealing with a marginal science that was not considered worthy of experimentation and questioning? But as I researched further, especially in journal entries and books, I found that biospherics had been fully conceptualized, albeit not entirely understood.

Vernadsky's pioneering work in biospheres, with some help from Eduard Suess, has propelled the field of biospherics to its current state. It remains to be seen whether biospherics will receive increased attention and funding in the future. The only certainty is that any experimentation in the field will always be inextricably tied to the originator of the biosphere concept, Vladimir Vernadsky.

Biosphere History: Early Experimentation

Gil Libling

"The history of biospheres, how exciting," I thought to myself when Professor Antonovics first introduced the topic. I could already see myself sunk under a pile of old books looking for clues as to who first studied self-sustaining ecosystems, and how they went about doing so. I was already feeling nauseous from the smell of old books stacked at the basement of the library. This was not really my impression of a fun time. As my research progressed, however, I began to find the topic perpetually more interesting. I was surprised to find that it was only really within the past forty years that experiments on self-sustaining ecosystems have been performed and officially recorded. The first biosphere ideas were focused on determining the smallest closed container that would be required to support a human being. Its main purpose was to try and develop a mechanism to aid space flight. Thus the main biosphere experimentation times ran parallel to the space race years.

The first documented biosphere experiment occurred in 1961, when a brave Russian named Evgenii Shepelev decided to encase himself in a steel casket along with eight gallons of green algae. According to calculations, these eight gallons of *Chlorella* under sodium lights were supposed to supply sufficient amounts of oxygen to be self-sustaining for one man. So brave Shepelev shut himself in this steel case; hey, on the blackboard his theory made perfect sense! But you can't breathe with theories, and after about 24 hours in the casket, Shepelev crawled out. The staleness of the air drove Shepelev out of his experiment. But he exited his experiment with glory and the knowledge that he was the first man on record to attempt such a study. These ideas concerning biospheres have driven other scientists to perform further studies. In 1968, Clair Folsome attempted another biosphere project while consulting for NASA. Folsome gathered microbes, a specific volume of air, and several other aquatic elements, and placed them inside a laboratory flask. Although this experiment was less "radical" than Shepelev's (seeing a man gasping for breath in a steel box may appear slightly more amusing than seeing micro-organisms swimming in a test tube), it proved to be the more practical approach to the study. Folsome provided the first true closed ecological system for scientific study.

These two early experiments paved the path for further biosphere studies. They largely attracted NASA and other space organizations, and have served as the building blocks of ideas for the Biophsere 2 project.

NASA Takes the Helm

Eric Dosch

In the 1950's, the American and Soviet space programs were in a major race to place human beings in outer space. It was in the development of life support systems that biospheres first became relevant. The space programs of the U.S.A. and Russia faced the critical problem of having enough oxygen for the astronauts, and so they examined the ability of plants to produce oxygen. In 1961, experiments were conducted with the alga *Chlorella*, to determine its suitability as both a food and oxygen source. *Chlorella* was found to be useless as food, but it was shown to have potential for oxygen production by the Russian Shepelev.

The research done on biospheres during the early space years did not lead to the development of a practical self-sustaining system. Instead, both the U.S. and Russia relied on mechanically controlled environments. Oxygen and water were carried on board the spaceship, and discarded when used. It is not surprising that biosphere technology was not really incorporated into the early space program. After all, if scientists were willing to throw away most of a space ship during its ascent into orbit, then why attempt to recycle relatively small amounts of oxygen and water.

In recent years, the approach of the early space program has changed. NASA has embarked on a program called Closed Life Support Systems (CELSS) and a follow up referred to as the Advanced Life Support Systems (ALSS). Biospheres are once again being examined because future space travel cannot afford to be not self-sufficient. Therefore, projects are underway to create a combination of bio-regenerative systems and mechanical systems. Future spacecraft will incorporate plants that produce oxygen and also serve as a food source. The hope is to create a closed system that can rely on natural processes more than mechanical ones. It is clear, however, that NASA does not believe a true self-sustaining system will be feasible or practical anytime soon. Perhaps in a few hundred years, space travel will use true biospheres, but I believe that environments will still be computer controlled, with only the appearance of a natural system.

The Social Context of Biospheres

Suma Potiny

If there is one thing I have learned during my first semester at Duke, it is that society has a strong impact on science, so studying the sociology involved in a scientific endeavor is just as important as the "technical" science involved. Thus realizing the significance of sociology to science and being a person who has always been interested in people and their opinions, I jumped at the chance to study the sociology of the biosphere project.

The task was certainly not easy, however. We found that the hardest part of the project was deciding what to research. With our conflicting schedules and varied interests, my group decided to divide the assignment. Patrick chose to research the past public opinion of the biosphere and Thema chose to investigate the scientists' opinion of the biosphere project. Still unsure of which angle I should take and being unfamiliar with biospheres, I decided to do some research on my own to find an appropriate topic. I felt that the best indication of public opinion was to examine the media, so I turned to the newspaper. One of the first things I noticed was that the amount written on the biosphere project decreased immensely after the failure of the project. The few articles that were written about the biosphere often ridiculed the project for its management problems and poor scientific method. I even found an e-mail written by a student at Arizona University near where the project is located who did not know about the project. This indicated to me that the public interest in biospheres declined. The first question I had was: Why did this decline in public interest occur?

Janis also brought other questions regarding the financial aspect of the project to my attention. He wanted to know why the billionaire Edward Bass funded the project and how he became involved. Also, since the research has recently been taken over by a private university, Janis was curious as to why this occurred and why the public does not fund the project.

Hence, a topic was born. My task in the project was to uncover the public opinion of the biosphere today and relate that to its effect on the future of the biosphere project. In addition, I investigated the reasons for private funding of the project by an individual as opposed to government, and what this indicates about public opinion.

After conducting a thorough Internet search, and database search of all the magazine articles written about the biosphere project within the past four years, I came to several conclusions. First was that there were several reasons why the interest in the biosphere project declined. One proposed reason is that people may believe, after the first failed attempt, that it is impossible to engineer a self-sustaining biosphere. As a tour guide for the current project puts it, "Biosphere I is still the best." Also, many have a negative opinion of the whole project, as I mentioned earlier.

Although interest in the biosphere has declined, it has not completely disappeared. Recognizing the decline in public interest, the biosphere project has been opened to the public. A primary motivation for this was that the managers and scientists felt that this would help to convince the general public to accept synthetic environments. They view the biosphere of today as "a valuable tool for educational outreach."

It certainly seems to have worked to a certain extent. The current research project in Arizona has become a tourist attraction, almost like an amusement park, that is heavily advertised. In fact, many writers compared the project to Disneyworld. I even found one article where the writer visited the site and wrote his general impression of it, as well as the opinions of those around him. Describing the biosphere as a "unique atmosphere", he seemed to view the project as a resort/museum. In other words, the experience was fun as well as informative. Another woman who he talked to seemed to agree, saying that she found the project to be "educational". Thus, the public interest in the project is increasing, although for different reasons than before the failure of the biosphere.

In regards to the funding of the project, I found that the project was funded by a millionaire named Edward Bass from Ft. Worth, Texas. He seems to be interested in the project for two reasons: the cause (to discover how to create a biosphere that will replace the one we are living in now when environmental damage takes its toll) and the money. He calls himself an "ecopreneur", but it is obvious his contributions are not completely philanthropic since Bass hopes to license the technology that makes the biosphere work. My findings inspired yet another question: How did Bass get involved in the first place? Apparently, the biosphere project has its origins rooted in a commune called "Synergia Ranch". This commune was ecologically oriented and its members were obsessive, spending almost sixteen hours a day working on the current project of the commune. Bass became involved with this group by helping out with their theatrical productions and projects or funding their endeavors. Since many of the initiators of the biosphere project were members if the commune, it is no wonder that Bass funded the biosphere project, especially since he can afford it.

Recently, the project has been turned over to Columbia University in New York, a private university. A major reason for this transfer is the hope that project can be considered a serious research endeavor. This could lead to public funding in the future since researchers involved will apply to funding agencies for grants to expand existing programs in global change, ecology, and biogeochemical cycles. Obviously, it is not believed to be a serious research endeavor and that is why it is not currently funded by government.

Overall, I found the answers to my questions concerning public opinion of the biosphere and its funding. It may not have been easy, but the difficulty made the discoveries all the more exciting. Not only did I learn a great deal about biospheres, I learned how to conduct research in a large group. After all, in real science, people work together to speed up the process, instead of doing their own individual projects. Therefore, I gained a valuable life experience from this project that will help me in college and beyond.

Public Perceptions

Patrick Bardill

To present some of the sociology of the Biosphere 2 project, I decided to study public reaction to the project. I focused mainly on the period before 1994. To examine newspaper articles I searched the LEXIS/NEXIS system of newspaper indices for the specific aspects of the Biosphere 2. The system was probably the most frustrating aspect of my project because it frequently found more than a thousand results and told me to try new search parameters.

After the first biospherians were sealed in the compound, public reaction seemed to peak when problems were found in the project. The public seemed to enjoy the follies of the biospherians and the managers. Repeatedly, newspaper columnists ridiculed the science of the biosphere, the management, and the general soap opera that seemed to be orchestrated around the project. The new crop of biospherians generated some media attention, but not nearly as much as the takeover of the management of the project by Edward Bass. The only interest expressed in the science involved in the project seemed to be a desire to ridicule it.

I believe that the public enjoys ridiculing scientists when it can. It is no secret that many people believe scientists to be of a different class, perhaps not even human. When scientists show that they too possess human frailties, people are inclined to seize upon such an event.

Overall, it seemed odd to associate sociology with the science we were doing with self-sustained ecosystems. Perhaps this is because the experiments of the class were so small that they seemed to have no repercussions on human existence. However, the experiments that other members of the class performed are at the heart of the Biosphere 2 project. This makes the experiments more relevant and sociologically interesting. The real science underlies the pseudo-science and the drama of the Biosphere 2 project.

Literature (or the lack thereof)

Molly Puente

I started my search looking up just the word "biosphere" and ended up with hundreds of citations, most referring to Biosphere 2 or Man and the Biosphere Project, which did not really address the issue of the science of self-sustaining ecosystems. What I needed to find were studies that had looked at the long term consequences of an enclosed, experimental ecosystem with little human intervention.

My next idea was to look for the keyword "self-sustaining ecosystem." The result was several articles on how an ecosystem can rebuild itself back into a self-sustaining system after a disturbance such as mining or flooding. Once again, the actual mechanism of self-sustainment was ignored. I decided that the best way out of this rut was to search for "controlled ecosystems". After all, anything we were looking for would have to be in some sort of controlled environment if it was to produce good data. I came up with places like the Phytotron at Duke and the Ecotron in England, which had the facilities to manipulate temperature and atmospheric gases received by plants. Unfortunately, I found that yet again I had hit the roadblock of human intervention. The most promising program was the Controlled Ecological Life-Support System (CELSS); this NASA project was designed to create a fully sustainable system that could recycle nutrients in space. The lofty goal of the program seemed to match ours; unfortunately, the actual procedures of their project did not relate with what we had planned. While it seemed like they were creating a limited biosphere, the actual designs show the plants separate from the people, the energy source, and the water purification. While we want to see how all the components of an ecosystem interact, NASA is keeping these elements separate.

In a final effort to see what was out there, I tried browsing the web for information. I found the Journal of Life-Support and Biosphere Science. This publication dealt with engineering problems, such as controlling temperature in an enclosed environment and articles on various projects like CELSS. Perhaps this young journal is the beginning of more publications on the science of biospherics. I think that as we start running out of fossil fuels and the greenhouse effect can be seen more readily, there will be more interest in creating self-sustaining systems. Unfortunately, there is not a wealth of information concerning controlled, self-sustaining ecosystems currently available.

Population Genetics: How Low Can We Go?

Molly Puente

Being the pessimist that I am, I was curious to see how our biospheres could be doomed. Not finding much in the literature about ecosystems, I thought it would be interesting to see how one population can be destroyed in a biosphere through genetic mechanisms. We want to get the smallest possible sustainable system in terms of population size as well species diversity because our space is limited. However, I thought that perhaps the experimental group was making their initial populations too small. The best way I found to predict the possible problems of population size was to look at zoos which have brought back highly endangered species.

In order to have a sustainable population, organisms must reproduce. Reproduction may itself require large populations. For example, several species of birds will only mate when they are in a flock; unfortunately, if the zoo or captive environment does not have enough individuals to make a flock, none of the individuals will reproduce.

Another possible problem might be related to demographic stochasticity, which is the effect of chance on a population. The effects of chance events such as an infertile individual are much more detrimental for a smaller population, because each individual makes up a larger percentage of the population. For example, the population of dusky seaside sparrows when reduced to six members was destroyed because its last generation was all male and therefore could not reproduce.

Supposing that a small population made it to the following generation without some sort of failure such as an all-male generation, there are still problems caused by a small size. A small population will find itself inbreeding within a few generations. Inbreeding can be very dangerous to an individual as well as to a population. Most deleterious traits are recessive and can stay in a population for a long time in heterozygous individuals. When relatives mate, their offspring have a much higher chance of showing the recessive trait than if random mating were to occur. While this may not necessarily kill a population, it could endanger a population by having all members susceptible to the same pathogen or condition.

As you can see, my pessimism paid off. I found a way that the biospheres could be doomed if we stick with our original experimental plans. Our task with the biosphere project now must not only find a combination of species which can support each other’s lifestyles, but also a size of population which can support itself.

Experimental studies

a. The effect of species composition and diversity of consumers in biosphere stability

Jimmy Yu and Pei-Ju Chiang

We volunteered to tackle the prospects of constructing a self-sustaining closed ecosystem. We tried to avoid past biosphere experiment mistakes by keeping our systems simple, making replicates, and maintaining a control. We designed our experiment to test the effect of species composition of consumers on biosphere stability. We set up five sets of "biospheres" (closed containers) with four replicates per set. In all the bottles, we kept constant producers (*Elodea* and *Chlamydomonas*) and decomposers (detritus). We inserted a different consumer (snail, *Daphnia scapholeberis*, and ghost shrimp) in the first three sets of bottles, and in the fourth set, we combined all three consumers to increase the diversity of the system. The last set of bottles served as the control, with no consumers present in the system.

We began the project thinking that it would be an easy experiment to conduct. After all, there was almost an alchemistic aspect in our approach because we would choose almost any organisms we deemed fit for the experiment. However, we soon realized that "real science" was a lot more difficult than expected. For one thing, it was tremendously more time consuming than we had anticipated. Real science starts from scratch, an aspect we were not totally adjusted to. We spent countless semi-conscious mornings gathering equipment and performing the most menial tasks: filtering pond water, separating daphnia, and washing elodea leaves. As a result of the unexpected amount of preparation time, we will not have our results by the end of the semester. However, we plan to continue the experiment over the course of our years at Duke. We are hopeful that the results of our experiment will lead us to a patentable biosphere product in the next four years!

Perhaps the most enjoyable aspect of our experiment was that, as we would run into problems, we would go in search of people who might be able to help us. This led us to meet some of the most charismatic biologists at Duke. The two most memorable occasions were our visit with Dr. Dan Livingstone and our search for Dr. Elizabeth Harris. To figure out a way to distinguish Daphnia from other water fleas in pond water, we were referred to Dr. Livingstone to borrow a plankton net, a fine filter used to capture minute pond organisms. Dr. Livingstone, not only referred us to his teaching assistant for a plankton net, but also entertained us with an engaging discussion on the nature of Daphnia, and his research in mapping climate change through pollen records in western Uganda. Dr. Livingstone suggested that we add Chlamydomonas in our systems to provide a food source for Daphnia. This led us to seek the aid of Dr. Elizabeth Harris, the director of the chlamydomonas lab in the Levine Science Research Center (LSRC). It was our first trip to the LSRC building and we soon discovered just how immense the building was! We wandered around confusedly for nearly an hour before locating Dr. Harris' office, where she graciously gave us a supply of Chlamydomonas.

There have been a few times during the experiment (especially during long, tedious set-up procedures) when we felt somewhat dejected at our slim chances of constructing a self-sustaining system. However, as if by magic, someone would always come along and pick up our spirits by asking us questions about our project, and commenting on the "impressive" appearance of our experiment. Rejuvenated, we would then continue our tasks with renewed determination. We are proud (and very relieved!) to say that the set-up for our project is near completion right now.

Regardless of the outcome of the experiment, we both feel the most important lesson we will take with us from this project is learning about the true nature of "real science" (coming up with experiments to test ideas, setting up the experiments, gathering equipment, dealing with unforeseen obstacles). Conducting this experiment has allowed us to appreciate not only the complexity of self-sustaining ecosystems, but the hardships and difficulties of the scientific process as well. This knowledge will, undoubtedly, serve us well in our future endeavors in science.

b. What level of plant productivity is needed to sustain consumer biomass?

Rabia Ali

My aspect of the Biosphere project was dealing with respiration and metabolic rate. I was trying to answer the following question: What level of plant productivity is needed to sustain what level of consumer biomass?

I began my research by directing myself towards the easiest way of obtaining information, nowadays the internet. But I did not obtain any concrete facts to answer my question. So after weeks of laziness and procrastination I turned to good 'ole Janis to guide me in the right direction. "Go to the Bio Sci library", responded Janis to my desperate call for help. After one quick look at the bioenergetics books I had picked up, Janis blatantly stated, "No, these books are too complicated". So off to the Bio Sci library I went again, this time with Janis. After dredging up old ecology textbooks and smelling the malodorous smell of the bleak and decrepit library, I finally breathed a sigh of relief because I now had the information I needed and was out of that dull library.

A Russian named Evgenii Shepelev had pondered some of the same questions as I did. In order to determine the amount of oxygen needed to survive he went to the utmost extreme by encasing himself in a casket with green algae. Now that's devotion to science!

Animals obtain energy mostly through the oxidation of foodstuffs, and their consumption of oxygen can therefore be used as a measure of their energy metabolism. Metabolic rate can, in principle, be determined in three different ways. The first is by calculating the difference between the energy value of all food taken in and the energy value of all excreta (primarily feces and urine). The second method of determining metabolic rate is from the total heat production of the organism. This method should give information about all fuel used, and in principle it is the most accurate method. The third measure that can be used to determine the metabolic rate is the amount of oxygen used in oxidation processes. The reason oxygen can be used as a practical measure of metabolic rate is that the amount of energy produced for unit of oxygen consumed remains nearly constant, irrespective of whether fat, carbohydrate, or protein is oxidized.

The primary productivity of a community is the rate at which biomass is produced per unit area by plants, the primary producers. It can be expressed either in units of energy (e.g. joules m-2 day-1) or of dry organic matter (e.g. kg ha-1 yr-1). The bodies of the living organisms within a unit area constitute a standing crop of biomass. Biomass refers to the mass of organisms per unit area of ground (or water) and this is usually expressed in units of energy (e.g. joules m-2)) or dry organic matter (e.g. tons ha-1).

WHAT?! Basically ten times as much plant is needed to satisfy an animal and allow it to survive.

c. The Reductionists: researching the giant failure

Pouneh Rajaii, Dave Naeger, and Steve Perret

In the deserts of Arizona, there sits a colossal testament to marginal science. When we studied Bioshpere II, the most outstanding qualities were the amazing complexity of the system, and its irreproducible nature. Fascinated, as the experimental group, we set out to examine biospheres anew. Inspired by a class discussion in which we pondered how one would create the most simple self-sustaining ecosystem, we boldly attacked the most basic of biospheres: The One Plant System (which shall henceforth, in the spirit of NASA's penchant for acronyms, be referred to as TOPS). We will use TOPS to follow a reductionist philosophy, which inherently involves reproducibility and simple starting experiments. Theoretically, information acquired through experimentation with TOPS will be the basis for developing and understanding more complex systems.

Looking back, one of the first things we all learned in biology is that nature operates in cycles, and, indeed, to develop experiments with TOPS the first thing we looked at was the viability of nutrient cycling. Specifically, we would like to compare the rates of carbon dioxide and nitrogen cycling in the presence and absence of decomposers. In order to do so, we set out for the lab, with its dizzying array of graduate students, chemicals, and little water buggies. After sketching our course of action on large white boards in the hallway (the ephemeral repository of ill-formed ideas), our first venture was the culturing of bacteria that we would use in half of our TOPS experiments. We went out to the tanks behind the Biological Sciences building, and dredged the two-foot abyss in search of the little beasties. We then diluted the pond water samples, plated them, and isolated several bacterial strains for use in our TOPS. The next step was to annihilate plants for placement into TOPS, which proved to be more difficult than expected; much time was spent wondering how we could kill the plants without altering their chemistry too much. To date, we have set up twenty-four TOPS for use in our experiment. Four of these systems were prepared with living plants, for use as controls, and of the remaining plants which were to be killed. Ten were frozen and ten were autoclaved; all of the plants were sterilized using similar methods. In each of these above plant groups, (live, frozen, and autoclaved) bacteria was added to half of TOPS. What currently remains is to measure the release of nitrogen and carbon dioxide from the plants.

Thus far, we have yet to further our knowledge of nutrient cycles experimentally, but we have learned several interesting things about biospheres, science, and other enigmas. We have learned that biospheres are amazingly complex, and even our romper-room, uni-level TOPS requires much management and involves many variables. Also, we have discovered that science is not the "happy-go-lucky" endeavor that it seems to be neither is it the extravagant, "money-laden" operation that popular culture imagines. In fact, science does involve many unanticipated problems, some of which can be solved by a small grant of five dollars and forty-nine cents from class funds, and a visit to the pet store.

One of the things that most surprised us was the actual laboratory process. We learned that experimentation is often a slow, tedious, yet creative venture. At times, we engaged in a veritable tempest of activity and actively confronted a flurry of objectives; while at other times, we eagerly awaited the agonizing resurface of sterilized test tubes from the autoclave U-boat. During these suspenseful hours, we consulted with the graduate crew, and the submarine captain Herr Janis (who, as the autoclave door is being sealed, has been known to exclaim "Dive! Dive!" with a thick German accent). In fact, the upcoming exciting chapter of our voyage will include Andy Allen, a graduate student who is an expert on nitrate measurement, and continuing to consult numerous graduate students who have already rescued us from the treachery of our own naïveté. These graduate students have been quite human, and we were surprised by the observation that they do not actually live their entire lives as lackeys, shackled in the dark comers of macabre laboratories.

d. Modeling the nitrogen cycle: progression towards recursion

Jake Woods

"Sure, " I said, "I'll do the modeling."

Two days later, I was wishing for a shotgun and a couple of shells - one for my computer, and one for, well, I can leave that up to imagination. What had I gone and gotten into? What could be modeled? Where should I begin? These and various other questions had begun convincing me to give up on the project before it started.

Fortunately, I was not alone in the world. No one else had a clue what to model either! However, in a class discussion regarding the construction of a biosphere, Dr. Antonovics dragged us tooth and nail to an interesting conclusion - this might be harder than we thought. The entire problem we encountered that day was the nitrogen cycle. In order for a plant to have a useable supply of nitrogen, it either has to be already present in the environment, released from dead plant matter, or fixed from atmospheric nitrogen. In order to assess what comprises a sufficient supply of nitrogen, we had to calculate quantities such as the initial amount of nitrogen in the system, the amount taken up by biomass, and the amount released by decay.

Certainly enough, I had a project dropped in my lap, and had plenty of time to do it. Or so I thought. Three weeks later, I still hadn't given the problem much thought. One Saturday, I had been considering the problem rather heavily, and so that night (this has to say something about my social life ...), I sat down and sketched my first model of the nitrogen consumption in the system.

It was interesting, but did it make any sense? I liked it, but the more I looked at the model the less sense it made. I had a half recursive, half instantaneous function which I couldn't resolve in any one direction. My function for decay was recursive, my function for uptake wasn't. This, I finally decided, was a problem. For the next few days I studied the half that was non-recursive in the hope that I could find some sort of loophole in my work that would allow me to express the problem differently.

Suddenly, it occurred to me that since the uptake depended on population, that substituting the population function for my uptake function, then multiplying by a variable-rate uptake entity, the uptake could in fact be expressed recursively. Now I only needed to deal with the fact that I had left the English-speaking world in favor of Math-ese.

Substitution of this new concept was nearly easy; a few mechanical mistakes were located and dealt with after reviewing the material with the entire group. I realized the key relationship in the system was that between the ratio of decay to uptake and the initial amount of nitrogen. Eventually, since population controls both the decay and the uptake, the two rates will reach an equilibrium. The closer they are to begin with, the sooner they reach equilibrium. So it seems that creating a stable biosphere, or ecosystem, depends on providing enough of the nutrient initially to prevent collapse of the system before decay replaces nutrients. This is true, of course, only if the amount of nutrient is not toxic in and of itself.

As arcane and useless as this may seem, it is actually very relevant to the work done by one of the experimental groups. Pouneh, Dave, and Steve are working out the measurements of the quantities I am trying to calculate; in the end, the rates might even equal each other, plus or minus a standard deviation or three.

I think the most startling thing I noticed about this project were my own work habits; most of my progress was in short, intense work sessions, with long layoffs in between while I contemplated other problems. Is this science? Or just learning? Maybe there is no real difference.

e. Modeling the carbon cycle
Alan Ramin Mortezaie-Fard
[No contribution received]

Big Science Versus Big Business: is reconciliation possible? (A.K.A. how to become a Republican)
Louise Vaz

When I first started researching the commercial aspects of biospheres, I was not very enthusiastic about the prospects ahead. I would have much rather have spent my time in a lab designing and conducting experiments. Indeed, I had volunteered to fill this vacant slot because the other topics of interest to me were already filled. Besides, I figured that this would reiterate how much I did not want to go into business in the future. By the end of this project, I came out with a totally different perspective on the role of science in today’s society.

I entered the research phase with a rather elitist mentality toward the idea of capitalizing on pure science. Basic research, I felt should benefit the whole of society and not come with a price tag attached. Moreover, I viewed science and business as two separate entities; one composed of intellectuals the other of greedy capitalists.

The bulk of my research was obtained through the Internet. I thought that this would be a relatively easy task. What were a bunch of legal terms compared to Einstein's theory of Relativity that I plowed through for my history class just a week before? Was I in for a surprise.

My first step was trying to figure out how to obtain a patent. The experimentalists were eagerly working on creating their own biospheres, and we needed to be prepared. The first question I wanted to address was what happened after we discover something. The answer was relatively simple: obtain a patent. A keyword search brought me to the U.S. Patent Office homepage and that's where my troubles began. I found out that the process to do so is decidedly long, arduous, and costly.

I did a search on patent lawyers, and I came up with a myriad of names. I chose a couple, randomly, and wrote to them via email, explaining my project and that I needed help. I got the most enthusiastic reply from Mark Ogram, of Ogram & Teplitz, P.C., in Tucson, Arizona. Mr. Ogram is a registered patent attorney with over fourteen years of experience in intellectual property law: his virtual office is (http://silkpresence.com/patents/). Mr. Ogram reiterated the importance of obtaining a patent attorney, since the patent process is quite complicated and complex, not to mention time-consuming and overwhelming to those unfamiliar with the procedures. The attorney will be able to better differentiate between every single claim that your patent professes and those of previous patents, so as to make the chances greater to obtain a patent. He also waged that we should maintain our ideas as secret as possible. I consulted with Mr. Ogram as to how to start a company, or perhaps the prospect of selling our services to a consultant. To this, he responded "I recommend though that before you use any consulting services or propose your invention to anyone else, you should secure at least some patent protection". He suggested the use of Provisional patents which give the inventor a year to further develop the invention, determine the marketability for the product, obtain funding at an economical cost of $495.00 (within our FOCUS budget!), as compared to the $3000-$6000 it would normally cost to obtain a patent.

While our FOCUS class began to get excited about marketing our new product, I soon discovered that several other biosphere companies already existed, and other scientific supply companies sold biospheres as well. Two scientists, Dr. Joe Hanson and Dr. Clair Folsome founded Eco-Sphere. Producing EcoSpheres for 15 years, this company has sold these systems worldwide to science museums, schools, and corporations. The Paragon Space Development Corporation was started three years ago by two Biosphere II participants, Jane Poynter and Taber MacCallum. They have pursued the research and design of miniature biospheres as scientific instruments for environmental test and control applications.

My next question was, "so given these companies exist, how long have we been interested in the commercial aspects of self-sufficient ecosystems?" My search brought me back to the U.S. Patent Office where I found literally hundreds of patents filed dealing with biospheres. Most of these patents were through Space Biosphere Ventures company in Oracle, AZ, where the current Biosphere II is located.

On November 7, 1997, my FOCUS class went on a trip to Beaufort, North Carolina to hear Dr. Jonathan W. Nyce, of EpiGenesis, give a lecture on intellectual property and the bridge between basic and applied science. Dr. Nyce of East Carolina State University started his own company after discovering a drug for asthma. According to Dr. Nyce, it is best to have more than one commercial product in order to form a company. This is important because a significant amount of resources is needed to back up the start of a company. Often, smaller companies will partner with a bigger company that has larger amounts of resources and higher competitive advantages. Companies, and people, need to make a profit in our economic system; and therefore, there is a need to preserve intellectual property rights. Often, though, shares of the company's profits are reintroduced into basic research. In this, the cycle is self-perpetuating. However, the cost of advancing a product from the bench to the public is expensive and there are risks.

This brings to question the debate of basic versus applied science. Basic science is discovery for the sake of discovery without immediate practical application. There is need, however, to think of the practical in forming a vision for the future. Academia stresses the importance of publications. If Dr. Nyce had solely published the results of his discovery, the likelihood of this new drug being available to the public is a lot slimmer had he not taken the course of action and filed a patent on his discovery and started his company. There is the need to take discovery all the way to the public, and not have it available to only fellow scientists and academics. The hardest part in convincing scientists that entrepreneurship is not immoral is trying to dissipate the notion that an industrial career is an anathema, analogous to “prostituting oneself”. Basic science has always had a high moral ground, coupled by the fact that basic science is also called “pure science” which has connotations of goodness when compared to “applied” science that sounds very mechanical and business like. As I learned, entrepreneurship is not a wrong motivation. If you don’t patent, you cannot take it through the developmental process and have it available to the public. In fact, academia has begun to change its attitude toward applied science. They have established patent and trademark offices (Duke included), and even own stock in the companies of their scientists.

The most difficult part of this research project was accepting that the view that I had about science was rather unrealistic and nearly utopian. The science that I idealized revolved around scientists helping one another, where the pursuit of truth was a cooperative effort. I was pessimistic about the involvement of business in science, and I felt that to obtain a patent and market the discovery would be cheapening the process that got it there in the first place. In a society based around money and materialism, I hoped that science would remain untainted by such capitalistic schemes.

Through my research, I have found that though some aspects of pure scientific elitism are true, science is inherently linked to capitalism and affected by the nature of man. Academia has geared science to that of publication. One is not a good scientist unless he or she is published. Mr. Ogram writes, “The way to bring an invention into service to humanity is either through publication or through patenting. Publication may serve the function, but all too often the costs to develop an idea into a product are so great that no one will invest the money unless they have some level of protection to assure that they will be able to re-coup their investment. Only a patent can give them this assurance.” Disappointment and failure often mark the race to discovery. Competition is stiff, and the first one to an answer will come out on top, regardless of the way he or she obtained the information, or at what expense. I found this very sad, but because this is the way that our society has structured itself, I find that there is little that we can do about it. In fact, if we don’t maximize our output, or take full advantage of our opportunities, say for example, obtaining a patent and making a company, we are liable to be left in the dust.

So-what to do? Should we succumb to the capitalistic ideals of the society in which we live in, or should we try and rebel against the conformity that dictates what we deem moral. There is no simple answer for this. The one thing that I recommend, is that every science student, intending to pursue research of any sorts, takes several courses in intellectual property law and business. They can then therefore decide whether research is what is best for them. Throughout my journey, I found my beliefs questioned and my thought-processes working overtime. I came out of this project slightly crushed, perhaps even disillusioned by the fact that the science that I was taught in secondary school and college was and is not the science of the real world.

Summary

Stephen Perret

When at the end of the course, we discussed as a class what we had achieved, we realized that we had indeed in large part avoided the pitfalls of our caricature of science-fair projects. Our biosphere research was far more sophisticated than a "bios-fair" project. We searched real libraries for original sources, we made numerous ventures into the lab, found out about patents, and we were even prepared to form our own company (like bio-medical researchers do in their middle age). In our study, we met with the late Russian scientist Vernadsky and have undertaken flights of experimentation with little ghost shrimp and other charismatic consumers. In fact, although we didn't do any " big science" with huge grants, or enormous domes in the desert, we did succeed in doing research whose scope was much broader than the average science-fair demonstration or even perhaps Biosphere 2. We cooperated, and instead of scrambling for blue ribbons and first prize stickers, we learned together as a class. We found science, peering into autoclaves or struggling with lawyers on the Internet, and as historians we realized that like wars and countries, sciences have beginnings but perhaps no end.

Like our friend "brave little Shepelev", we took our research and experimentation seriously, well not quite to the point of locking each other up in caskets, but realizing that in a small way, and collectively, we were becoming seasoned veterans of the scientific community! I think Janis was disappointed that none of us became totally obsessed (although Louise was accused of becoming too intense on the internet), or by some grand revelation suddenly eschewed chemistry ("the science of the known") and in favor of biology ("the science of the unknown"). But we have learned that there is real science, and that this wasn't a bad sampler. Indeed, some of us may keep working on our biospheres after finals are done!

Epilogue: "*Is that all there is....* ", Peggy Lee, 1972

Janis Antonovics

I should start with a group confession. Yes, we did go out and buy a ready-made, commercially available biosphere. It even came with a marketing ploy; buy a snazzy lamp as well as the biosphere, else no deal. But if some FOCUS courses can go to Moscow, ours surely could afford this little indulgence. The biosphere when it arrived, created considerable excitement, perhaps more so among my graduate students, than among the by now blasé, undergraduates. I even managed to get our theoretical ecologist, Dr. Will Willson, to stare at it with some modicum of awe.

It was a cute, glass sphere, 6" in diameter (I felt guilty about buying a bigger one) filled almost completely with quite clear water, in which floated some very pretty plants. And while we couldn't quite bring ourselves to call them "charismatic megafauna", lo and behold, careful observation revealed there were indeed consumers: two snails, a few water fleas, and some shrimp-like amphipods. The biosphere was cradled protectively and eventually found its home in Blackwell dorm, where I think it still sits. Is the water clear? Are the megafauna still alive? Are they evolving higher (intelligent?) forms of life?

I was disappointed the class didn't name the biosphere. I did encourage some names, like ‘Focusphere’ or ‘Blue Devil Dome’, but somehow none of these stuck. I sensed that we were a bit underwhelmed with our store-bought biosphere. It can be done; here it is, yes; but is that all there is?

I admit my own enthusiasms were far less for the product, and far more with the process. My lab is a busy one, who needs new ideas when experiments are backlogged, and surely it is safer filling in the details of an existing science (in my case evolutionary biology) than trying to start a new one. But there remains in me a very strong feeling that there is a new and exciting science here, or at least a potentially huge branch of ecosystem ecology that has been neglected, and perhaps summarily dismissed because contaminated by the marginality of efforts like Biosphere 2 and the ad hoc efforts of NASA.

I am not an ecosystem scientist, nor an ecological modeler, but a scan through relevant journals in the Biological Sciences library with Molly (our "literature review" student) revealed no research that had even tried to answer many basic biological questions about ecosystems. There was a call for the study of self-contained ecosystems by Dr. Dan Botkin, a famous ecosystem ecologist in the late seventies, but his call seems to have gone unheeded. Indeed, the concerns of ecosystem scientists are with Biosphere 1, our own planet. Dr. Bill Schlesinger took our class on a tour of the FACTS project (Forest Atmosphere Carbon Transfer - another governmental acronym to be parodied at Christmas parties) where CO_2 is being pumped over replicated patches of Duke Forest to understand the threats we face as a result of man-induced global change. And ecologists, because they enjoy being in nature, presume complexity, presume interactions, and perhaps fear reductionism.

So the questions continue to buzz in my head. Do all self-sustaining ecosystems need three trophic levels, or can one suffice? Does increasing the diversity of species in a self-sustaining ecosystem promote stability? Is there a minimum size for the population level components in a biosphere? Does sexual reproduction promote evolution and stability in a biosphere, or does it destabilize it? What internal biosphere processes lead to biosphere collapse? Even the reductionist approach that the "experimental" students took in class seemed novel. For example, we could find no data on rates of release of nutrients from dead plant material under sterile conditions!

I am not yet quite ready to change my research area, but like Haeckel (who defined the science of ecology, but then did other things) it may be worth thinking that biospherics may be a future science.

So on with the laws of biospherics:

First Law: "Self-sustaining ecosystems minimally need one and only one trophic level".

Second Law: "Species diversity is an unimportant component of long-term biosphere stability".

Third Law: "Sexual reproduction increases biosphere persistence".

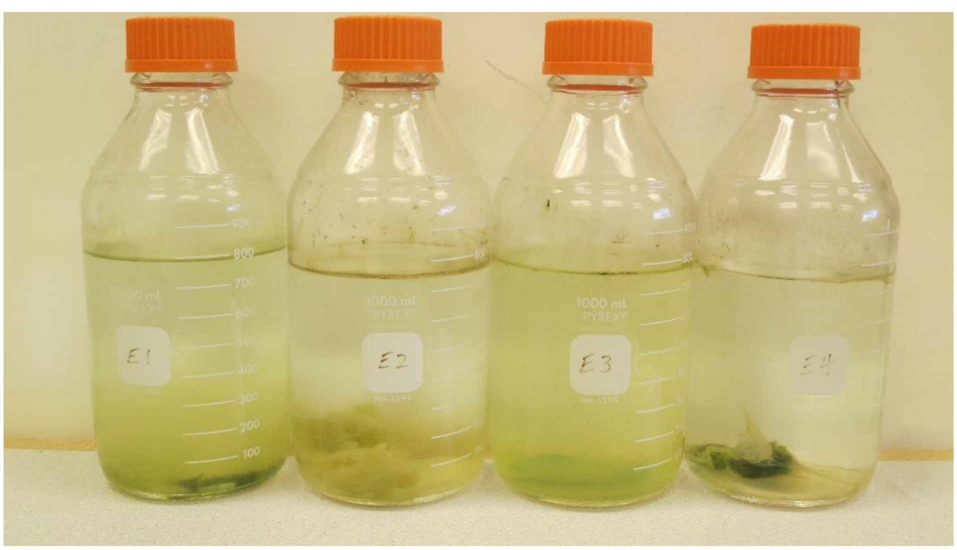
Fourth Law: “Biosphere collapse occurs when an essential resource enters a non-recyclable state”.

The challenge for experimental and theoretical biosphere scientists is surely to validate these laws or to prove me and my brilliant FOCUS class wrong.

Postscript:

Nearly thirty biospheres were set up by the class from pond water components in screw-cap bottles. Over twenty years later, most of them appear to be alive, at least as judged by the presence of green material.


A1
A2
A3
1000 mL
PYREX®

B1
B4
1000 mL
PYREX®

E1
E2
E3
E4
1000 mL
PYREX®


C1
C2
C3
C4
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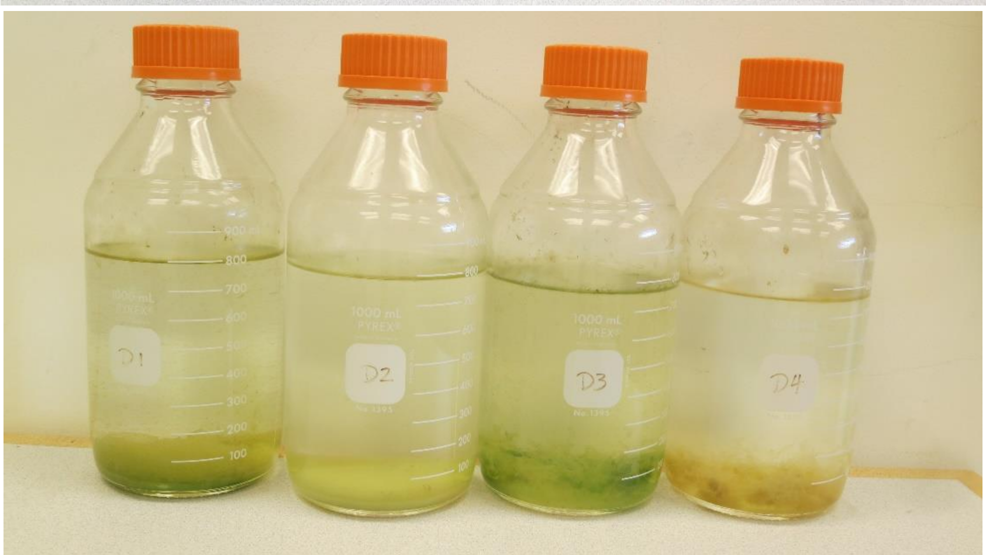
PYREX®

D1
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D4