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Human Ecological Dysfunction and the Value of Closed Biosphere Research

Hugo Blomfield
University of British Columbia
Canada

Abstract

This paper will discuss the potential danger of human expansion into the solar system with the current incomplete state of knowledge regarding Earth's complex ecological life support systems. The majority of space theorists see the vast resources of outer space as the key to our species' final release from biophysical constraints, providing solutions to ecological mismanagement and economic inequity across the planet. A critique of the Biosphere 2 experiment serves as the foundation for a contrary argument presented here. Recommendations for a new direction for closed biosphere research that would benefit our terrestrially bound society as well as our long-term future in space are then made.

Human-Ecological Dysfunction

The human species along with all life on Earth has co-evolved in the same materially closed, energetically open system under a certain domain of conditions. The evolution of this global system over billions of years has resulted in life's self-organization into a complex and nested arrangement of hierarchies. Each level within these self-organizing holarchic open (SOHO) systems is the product of certain interactions relating to material and energy flows. Within this nested arrangement, each hierarchical level influences the functions at adjacent levels (Odum, 1997). At the global level, the collective interactions of these SOHO systems have achieved a homeostatic balance, implying that all aspects and functions of this planetary system are in a self-regulating equilibrium. It is this planetary balance that is responsible for the evolution and sustainability of all life on Earth. This life support system is called the ecosphere[1]. Embedded within the ecosphere is the human economy, which is defined as the set of activities and relationships by which human beings acquire, process, and distribute the material necessities and wants of life. The economy therefore is not just a system of supply and demand shaped by national governments (Figure 1), but more fundamentally includes all activities by which humankind interacts with the rest of the ecosphere (Rees, 2002).

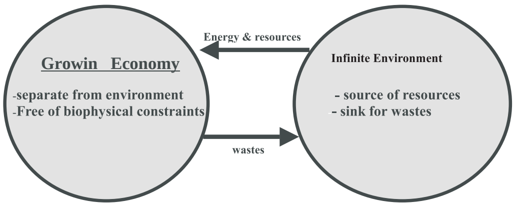

Figure 1: The expansionist's paradigm reflecting the relationship between the human economy and the environment. The majority of economic theory is based on this false model. Adapted from Rees, 2001.

Under this simple reality, the individual human is a subsystem of their society/economy while the society/economy is a subsystem of the ecosphere, which is a materially closed system with no outside inputs of resources[2]. Because of this, each subsystem can develop and function only by extracting available energy and resources from its host system located one level up the concentric hierarchy and by ejecting its wastes back into that same system. In other words, each subsystem is thermodynamically positioned to consume its host from the inside (Figure 2). What is different about human economies versus the economies of other forms of life is that in addition to our biological metabolism, humanity also has an industrial metabolism that, like our organs, requires a constant flow of energy and materials from and to our host ecosphere. There is no problem with this relationship for either system as long as material consumption and production by the economy does not significantly exceed resource production and waste assimilation by the ecosphere (Rees, 1997).

However, with an expanding global population and a globalizing political system that demands continuous economic growth, the speed at which the human economy is consuming the ecosphere is accelerating and thus the aforementioned condition is being violated. As a result we are seeing increasing disturbances in the productivity of Earth's ecosystems that will have dire consequences for the future of humanity.

Is Space the Solution?

Many space theorists and enthusiasts argue that space is an imperative destination for human economic expansion and that the vast quantities of resources located there will finally release our species from biophysical constraints. What the authors of these pieces, many of whom are funded by national space programs, are theorizing is not so much the place of humans in the universe but rather how space and its vast resources can be shaped and manipulated for the benefit of humankind. It has become clear to me that within the literature, there is little if any criticism of either the direction and impact of Earth-bound economic growth or the influence that such an expansionist paradigm would have on our fate if propelled beyond Earth's atmosphere. Certainly there is some truth to their argument; mainly that expansion into space would alleviate pressures on scarce terrestrial resources. However the avail-

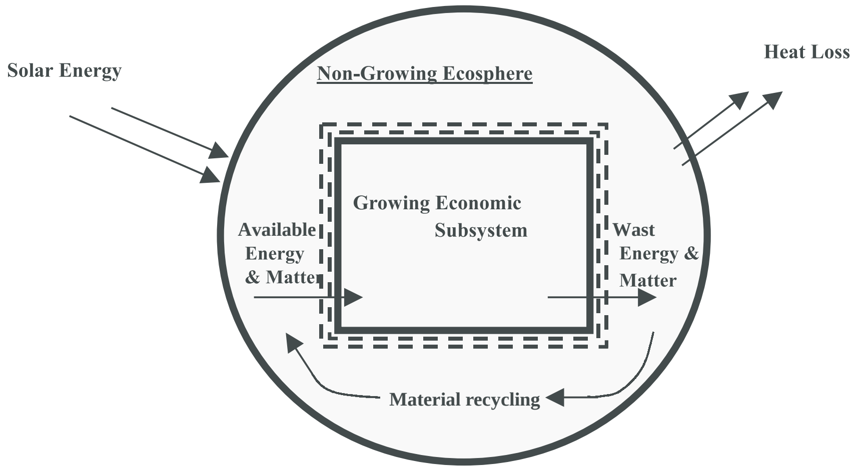

Figure 2: A more ecologically holistic model reflecting the embedded nature of the human economy within the finite ecosphere. Here it is clear that economic policies based on the model presented in Figure 1 are not sustainable and thus undermine the vitality of Earth's life support systems. Adapted from Rees, 2001.

ability of technology and massive quantities of energy aside, such a direction could prove fatal to our species if not accompanied by a change in our collective worldview towards the embedded nature of humanity within Earth's ecosphere.

It is theoretically possible for our species to live exclusively in the space medium, however our limited understanding of complex ecological systems jeopardizes the long term success of a meaningful number of humans living off the planet as well as the fate of those that remain terrestrially bound. For at the moment, we know of only one system that supports life to an extent where human civilization, and all its characteristics, is possible: Earth. So while we await advances in technology that will, in the future, permit the large-scale appropriation of extraterrestrial resources, it is imperative that our planet's space programs, hopefully in conjunction with environmental and developmental agencies alike, seriously commit resources to the study of closed ecological systems, in the likes of Biosphere 2, that attempt to mimic the materially closed, energetically open nature of Earth's ecosphere. Such research will contribute greatly to our understanding of the processes by which ecological systems self organize into states of homeostatic balance, and thus give us a better understanding of the evolution of our planet and its biophysical boundaries that all subsystems, including the human economy, must exist within. This understanding will help alleviate unsustainable resource depletion and waste emission, improving the conditions of life for a large segment of humanity. Hopefully, human perceptions towards their place in the hierarchy of SOHO systems that define our existence will positively shift in the process. As a spin-off to this most fundamental understanding of our planet, more in depth knowledge of closed biospheres will eventually allow us to reproduce scaled versions of the life supporting processes of Earth, thus removing the most fundamental obstacle to a permanent human presence in space.

Lessons from Biosphere 2

Biosphere 2, modeled after Earth, the first biosphere; hence its name, covers a 1.27ha area of the Sonoran desert in Arizona, enclosing an approximate volume of 200,000m3. The glass-enclosed mesocosm was designed and built to serve as a materially-closed and durable environmental research apparatus, consisting of five model ecosystems, representative of Earth's natural tropical and sub-tropical biomes, including desert, rainforest, savanna, mangrove-marsh, and ocean coral reef (Zabel et al. 1999). The system also included an intensive agriculture biome and a crew habitat that would support 8 crew members for a 2 year mission that would see them become completely sealed from the surrounding environment, and thus creating the world's first large-scaled, materially closed system (Figure 3). The underlying objectives behind the vision of Biosphere 2 were threefold: an aid to dealing with the "problems of the environment"; an experiment to understand the laws of biospherics[3] (Allen, 1991); and a ground-based prototype for the stable, permanent life systems needed for human exploration of Mars (Nelson et al., 1992). The fundamental goal of Biosphere 2 was to achieve 'Noosphere 1', the full and sustainable integration of human ecological, intellectual, and technical activity into our planet's ecosphere (Allen and Nelson, 1999). Such a realization depends heavily on a paradigm shift that requires humans to truly understand our position in the nested SOHO systems that sustain life on Earth, and is essentially what planners refer to today as sustainability.

During the first mission, shortly after closure, rapidly growing herbaceous plants thrived in the bright light adjacent to the glass walls and roof, resulting in a loss of less competitive rainforest biota, accompanied by a steady decline in oxygen levels in the artificial atmosphere. The crew spent much effort attempting to prune

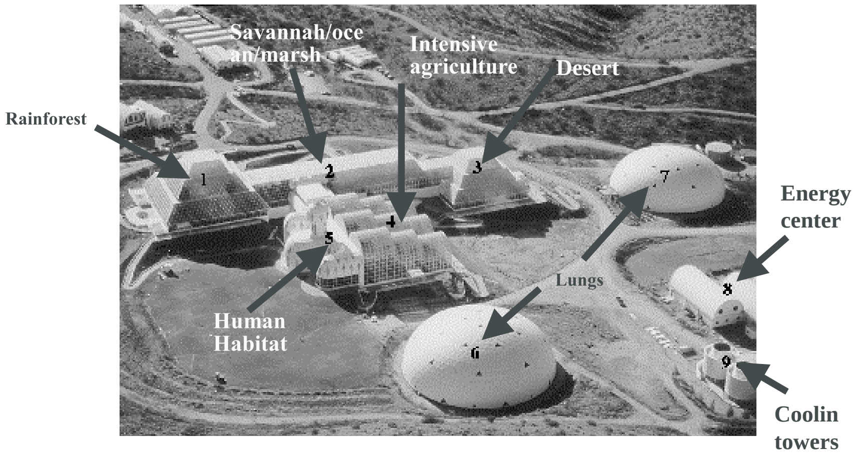

Figure 3: An aerial perspective of the Biosphere 2 complex. (Zabel et al. 1999)

vines and other weeds in order to arrest pioneer species in favour of later successional species while attempting to increase sequestration of carbon dioxide and to increase oxygen production (Leigh et al., 1999). This decision was clearly based on human perceptions. The amount of litter deposited on the forest floor drastically increased due to human pruning and competition between plant species and the subsequent increases in soil decomposition rates released increasing amounts of carbon dioxide (CO_2) into the closed atmosphere (Marino and Odum, 1999). It was also found that Biosphere 2's own concrete structure was sequestering significant quantities of oxygen, further degrading the quality of the atmosphere for human survival. Sixteen months after the system was closed, the crew made the decision to inject pure oxygen into the atmosphere, and thus the experiment failed its most important objective of remaining closed for the entire two-year mission.

The vision of Biosphere 2 to study the laws of biospherics was an appropriate one, however their methods of study adhered to their ultimate ambition of colonizing space. Earth's biospheric systems evolved over hundreds of millions of years, and thus even the slightest understanding of this process will make it clear that we must be patient in order to understand them. The Biosphere 2 experiment hastily strived for its ambitious goals without ever stepping back and evaluating the best possible methods of approach. In his official celebration of the Biosphere 2 project, Allen (1991) makes his ambition and anticipation for immediate progress entirely clear with comments such as: "Space Biospheres Ventures[4] (SBV) was on the verge of launching its own spaceship, so to speak, with eight people in it" and "...the fact that this same problem would have to be dealt with for a Mars or other space project - the sooner the challenge was met, the better!" The pressure to succeed at such an elaborate aspiration, especially considering the amount of media publicity and scientific scrutiny surrounding the experiment, potentially distracted its founders from using a more appropriate research approach or perhaps even a more appropriate objective all together. Humans were sealed within the system only months after its completion, and quickly began to manage it in accordance with their own social construction as to how an ecosystem should function. This combination of events in effect allowed no time for the self-organization of Biosphere 2's hastily assembled ecosystems, and thus they quickly shifted towards a domain of stability increasingly dangerous for its human occupants. Biosphere 1 (Earth) spent billions of years evolving before the introduction of humans into its system; Biosphere 2 should have learned from this previous research. As planners are taught, the creators of Biosphere 2 should have utilized a multi-step process in planning the objectives of their study. Pursuing three objectives at once, when some must be achieved before understanding others, is a process that is bound to fail. The root cause of this failure was the founding team's premature ambition to explore space supported by their underlying paradigm of utilization and not genuine understanding of the fundamental processes that support life.

A New Direction

In the previous sections of this paper, I attempted to explain a trend in human perception towards the life support systems of our planet that is inherently misaligned for the long-term health of our terrestrially bound civilization as well as future prospects of permanent habitation in space. Based on these arguments, and modeled on the innovative research conducted at Biosphere 2, I will attempt to suggest a new direction for our world's space programs that will benefit our future on Earth and in space.

Biosphere 2 was certainly innovative and expensive, however the value of better knowledge concerning complex life support systems is immeasurable. For this reason a more holistic closed ecological system project must have multiple sealed biospheres, for control, comparison, and replication. The multiple biospheres should all be located at similar latitudes and climates in order to duplicate the amount of incoming solar radiation, the only input into the closed systems. This extensive research project should also have a temporal dimension, in order to mimic the natural evolution of ecological systems. An imperative element of this is that the biospheres should be first closed for an extensive period of time without humans, allowing an extensive monitoring and evaluation process to improve our basic understanding of ecosystem self organization and the potential resulting atmospheres. Like Biosphere 2, the new generation of biospheres should be overstocked with redundant plant and animal species thus providing a framework for natural fluctuation in species composition and dominance before eventually reaching equilibrium. A thorough survey of atmospheric conditions and species composition can be conducted throughout the mission using space technology such as airlocks and extra-vehicular activity (EVA) suits; this would ensure that the closed systems are not breached.

Once a basic understanding of ecosystem self-organization has been achieved, human crews can be inserted into the materially closed biospheres. At least one biosphere should remain free of humans to serve as a control, revealing the progression of the system without the burden of human occupants. However, a large degree of uncertainty exists in understanding how crew composition can be altered in order to reduce the probability of failure of the kind experienced by Biosphere 2. The most noticeable characteristic of the Biosphere 2 crew was that they were all white western scientists. The values and beliefs of such a small segment of human society may be very different than a horticulturalist from a developing nation used to limited resources. The decisions made by these types of humans, in respect to their artificial environment and fellow crewmembers would most likely be very different. For this reason it would be beneficial to mix the occupational and skills backgrounds of the crews, creating a unique mix for each crew that then could be monitored and compared for successful adaptability to the limited nature of the closed system. The skills sought after should be unconventional in space science terms, and more those that would be beneficial to wilderness survival. Obviously technical and scientific skills would still be needed, but they should not exclusively represent the nature of the crew. At this stage of the research, the individuals selected must not be of the astronaut caliber that is continuously used in closed life support system research. Such a wider diversity of skills and occupations will help demonstrate to the researchers the types of skills and personality traits that future astronauts should adopt, rather than taking current characteristics of astronauts and seeing if they are compatible. Finally, different styles of command structure could also be researched, helping researchers to determine what the best structure would be for future long duration missions. A range of structures that could be used includes a military style hierarchy, a facilitation style leadership, or a structure left to the crew to determine. Such an aspect to the research would also provide a fundamental understanding of human social structure in relation to its embedded position within a finite ecosphere by studying which social structure was more successful in gaining maximum productivity out of their finite system, because as we have seen on Earth, current styles of democracy are unsuccessful at living within ecological boundaries. Perhaps through this research we can learn a new direction.

Conclusion

The purpose of this paper was not to develop a detailed plan for future biosphere research, but instead to describe a trend in human perception towards our planet that threatens to jeopardize our long-term survivability if maintained as we expand into the solar system. It was through this description that I highlighted the fundamental importance of closed biosphere research and the need to conduct it under a broader set of objectives, leaving a more detailed description of the objectives and mission architecture to another study. Essentially I am describing a vision for what is possibly the most fundamentally important knowledge to our species. The first step should be a realization that the primary goal of this research should not be to study how a pre-defined crew will utilize an ecosystem to explore space, but instead to better understand the fundamental relationship between humans and the finite ecological systems we are embedded within, while learning about what human skills and traits are best suited to live within their boundaries. This new direction will define a new beginning for humanity where we will be able to prosper throughout the solar system without the threat of self-destruction.

Correspondence

University of British Columbia
#433 - 6333 Memorial Road, Vancouver, B.C. V6T 1Z2. Canada.
dunon@interchange.ubc.ca

Notes

1 The more commonly known term for the sphere of life covering the planet is biosphere. This term however, does not adequately describe the interaction between biotic (living, e.g. plants and animals) and abiotic (non-living, e.g. climate and soil substrate) elements that form complex ecological systems. For this reason, ecosphere is the more correct term.
2 The small input of meteorites is so trivial in terms of mass that Earth is essentially a closed system.
3 Biospherics was the term used by the Biosphere 2 researchers to describe the processes by which ecological systems self-organize towards a state of equilibrium.
4 Space Biosphere Ventures was the joint-venture that founded, designed, and operated Biosphere 2

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