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A tri-modal nature of life applied for actualizing a win-win human-environmental relation and sustainability

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Abstract

We present empirical and conceptual synthesis and a revised model of life to help address the global ecological crisis. Given the state of world, the current paradigm that underlies life science appears insufficient to enable a solution to the crisis and may in fact be part of the cause of the crisis. We develop a distinct "sustained life" to complement our current paradigm based solely on "discrete life". We also present a three-model, multi-scale way of characterizing the original and fundamental nature of life. The multi-model can be expressed using a hyperset formalism as *life = {environment{ecosystems{organisms{environment}}}}*. This self-referential, closed loop hierarchy following Kercel (2007) explicitly prohibits fragmentation of any major sub-unit of life and prohibits separation of life from its essential environmental context (life support system and carrying capacity). We integrate work of 1) Ulanowicz and Patten, 2) Rosen and 3) Lovelock and Vernadsky who developed holistic characterizations of life at ecosystemic, organismic and biospheric organization levels, respectively. We propose adoption of this paradigm would enable actualization of a mutualistic win-win relation between humans and environment and long-term environmental sustainability. Finally, we examine implications and applications of these new scientific conceptualizations when linked to values, economics, society and development.

Keywords: life, discrete life, sustained life, sustainability, paradigm shift, holistic science, hypersets

1. Introduction

> English does not contain a suitable word for "system of problems." Therefore I have had to coin one. I choose to call such a system a "mess"… The solution to a mess can seldom be obtained by independently solving each of the problems of which it is composed -- Ackoff (1974, p. 21).

The current mainstream paradigm that underlies life science appears insufficient to enable a solution to the current global ecological crisis. The current paradigm recognizes only cells, organisms and individuals as the valid and fundamental units of life. While these "discrete" units – or unit-models – of life are clearly necessary, and the associated paradigm based on "discrete life" has advanced science for centuries, these ideas may not be sufficient in a world in which 1) humans have altered all ecosystems on Earth, 2) humans have pushed the fundamental life support capacity of Earth to its limits or beyond, and 3) problems are highly inter-connected and solutions must be multi-disciplinary and multi-scale in order to succeed. It is unlikely that we can extrapolate the cell-organism-individual paradigm of life from the past to make the systemic societal, community and global changes in understanding, behavior, technology, policy and culture needed to solve our human-environment crisis.

One "Grand Challenge" (NRC 2001) facing humanity, as we and many others see it (e.g., Wackernagel et al. 2002, Fowler and Hobbs 2003, Leigh 2005, Millennium Ecosystem Assessment 2005, Cabrera et al. 2008, Rockström et al. 2009), can be articulated in two central questions. What are the causes of chronic and systemic human environmental degradation? How can we stop and reverse it? This paper reports conceptual synthesis toward a paradigm shift in life sciences to meet this "Grand Challenge".

We propose the holistic summary of our global ecological crisis "mess" (Ackoff 1974) is this:

The fundamental, net human-environment relationship is antagonistic or "win-lose".

Therefore, our approach is to describe the crux of the problem and solution as a shift between two paradigmatic views of the fundamental relationship between life and environment. The prevailing paradigm sets as primary an *antagonistic relationship between life and environment* at the deepest level and between humans and environment by logical extension. The central view of this paradigm separates life and environment as distinct entities and is synonymous with Darwinian ideas of the story of life as “the struggle for existence”. An alternative paradigm emphasizes as primary a *mutualistic relationship between life and environment* (Fath and Patten 1998, Bondavalli and Ulanowicz 1999, Fath 2007). This conceptual framing integrates life and environment into a functional whole and seeks to understand the reciprocity and interdependence of the “co-evolution” of the two together. We develop and pose this alternative view as key to achieve a win-win relationship between humans and environment, which would then enable lasting and systemic solution to the global ecological crisis and achievement of environmental sustainability. We trace the history, key supporting concepts and models, and evidence for each paradigm, and propose both scientific and pragmatic societal cases for shifting to the alternative view.

Kuhn (1962) described paradigm shifts in science as natural, necessary and as much a human social process as a scientific process. Famous, archetypal and major paradigm shifts in science include those catalyzed by Copernicus, Newton, Darwin and Einstein, to name a very small subset. Ulanowicz (2009) made the case that an “ecological metaphysic”, including a “calculus of conditional probabilities” and the tools of network analysis, is now poised to provide a “third window” by which we view the world, transforming those mechanical and evolutionary pictures we have gotten from the “windows” of Newton and Darwin. This paper seeks to corroborate and elaborate on this ecological worldview that Ulanowicz (2009) has defined (see below for synopsis and three core tenets of his ecological paradigm).

A paradigm shift can be driven by a “crisis” in science and a pressing need for a better objective, formal explanatory theory to fit observed phenomena (Kuhn 1962). But a paradigm shift may also be sought for pragmatic reasons and for social application. Meadows (1999) wrote eloquently of the leverage that paradigms, and the power to transcend paradigms, provide for change in complex social-economic-environmental systems. Among her list of 12 forms of leverage for change, she ranked two related to paradigms at the very top. A cultural paradigm has leverage, because, as *the shared basis for action*, a paradigm has a powerful amplifier or multiplier effect that shapes many actions and their results. We suggest that only by radical and fundamental change at the paradigm level of life science – a revision not only in *what* we think about life and environment, but more importantly *how* we think about life and environment – can we see both the root cause of our current systemic crisis and the key steps in solving it. In addition to presenting an outline of this paradigm shift here, we seek allies to form an interdisciplinary project team for this effort, and we invite critique and assistance with brainstorming on next steps.

Working from the scientific perspective, and within science, we may consider two general options for a strategic approach – reductionism (aligned with analysis) and holism (linked to synthesis).

The basic process in reductionism is to break a problem apart and study sub-problems. By this approach we focus on climate disruption, species loss, energy limitations and other such problems separately. This approach has many benefits, such as disciplinary and specialist efforts on sub-problems that provide in-depth, detailed knowledge of causes, processes, key variables and relationships. The main risk of the reductionist approach in the present situation is that if a *systemic cause* of the global ecological crisis exists, focus on isolated sub-problems could make matters worse overall. By analogy, this would be like taking medicine to reduce unpleasant symptoms of a disease without addressing the root cause and having a false sense of improved health. Fiscus (2007) presented evidence for such a systemic cause by documenting simultaneous unsustainable trends and practices in conventional agriculture (loss of soil organic matter and vertical structure), university buildings (energy use, CO_2 emission and NO_x emission) and the U.S. food system (network topology different than sustainable natural ecosystems).

The alternative holistic approach is to consider the generalized human-environment problem as a whole. This approach entails addressing many or all of the symptoms at once, looking at other non-human or non-industrial life-environment relations as references, and going back to the drawing board to ask: What is the fundamental nature of the life-environment relation? The holistic approach also involves interdisciplinary collaboration and synthesis. The main downsides to this strategy are the technical and language difficulties, institutional barriers and slow pace of interdisciplinary work. The main benefit is the potential to solve multiple sub-problems of the global ecological crisis together or, ideally, to solve them all. Inspired by other holists and systems thinkers, and to pursue that great potential to solve the global ecological crisis at its systemic core, we work from the holistic strategy.

2. Framing the Problem

Humans threaten the environmental life support capacity for ourselves and other species. This general circumstance is paradoxical, since, based on mainstream biological and economic theories, self-interested and competitive behavior of individuals is supposed to lead to betterment for all. Instead, the multiplicity of chronic and systemic symptoms - arising from industrial societies and economies that predominantly emphasize competitive action for self-interest - suggests a deep problem. From this holistic perspective the most basic relationship of humans to environment appears clearly dysfunctional and suicidal. The net relationship in the short-term is that humans win (gain resources, grow, develop, etc.) at the expense of the environment (environment deteriorates and loses, resources are depleted, wastes accumulate). However, since we are dependent on the environment for life (and in fact not even clearly separable; see below), if this relation continues in the long-term, then humans eventually lose, too.

The specific details and evidence of individual human-environment problems are increasingly known, and many of the major sub-problems are full-blown crises in their own right. For empirical evidence we cite three major independent and synthetic monitoring schemes which all agree on the fundamental reality of systemic crisis: 1) the ecological footprint (Wackernagel and Rees 1996), 2) the planetary boundaries project (Rockström et al. 2009); and, 3) the Millennium Ecosystem Assessment (2005).

The ecological footprint uses rigorous scientific methods to account for gains and losses in the carrying capacity of the Earth and its ability to support human life. This approach accounts for both essential inputs to human society (food and other natural resources) and outputs from society (wastes exported to the environment). It emphasizes the finite areas (i.e., actual spatial extent) of healthy, functioning terrestrial and aquatic ecosystems needed for biophysical services including 1) human food, feed and fiber production, 2) livestock for meat and milk, 3) timber for wood, fiber and fuel, 4) fisheries, 5) infrastructure for housing, transportation and industry, and 6) CO_2 uptake and absorption of waste from burning fossil fuels (Wackernagel et al. 2002). Collaborative efforts to quantify and publish the global ecological footprint have shown that we overshot the carrying capacity of the Earth in the late 1970's or early 1980's and continue to run a deficit (Wackernagel et al. 2002, Ewing et al. 2010). This is a recipe for collapse – even using the current prevailing paradigm – as for all species that overshoot finite and essential environmental carrying capacity.

The highly collaborative planetary boundaries effort (Rockström et al. 2009) defined nine aspects of planetary processes essential for human life and development. They used these parameters to "define the safe operating space for humanity with respect to the Earth system and…the planet's biophysical subsystems or processes." Of the nine, the authors found three to be most severely beyond the thresholds identified as safe - climate change, alteration of nitrogen and phosphorus cycles, and the rate of biodiversity and species loss. As examples of their in-depth and comprehensive assessment, they selected 350 parts per million (PPM) as the safe threshold for atmospheric CO_2 concentration and 1 watt per square meter as a safe threshold for radiative forcing. They report that both have been exceeded greatly, with CO_2 at 387 PPM and radiative forcing at 1.5 W/m^2 (Rockström et al. 2009) at the time of their report. They similarly argued for the need to reduce anthropogenic reactive nitrogen fluxes to 25% of current values to remain within a safe operating space for this important biogeochemical cycle. In addition to defining these discrete Earth system indicators for sustainability – which they describe as "biophysical preconditions for human development" – they also mention repeatedly that all the boundaries are "tightly coupled" and thus must be addressed as an interdependent set.

The Millenium Ecosystem Assessment (2005, often abbreviated MA) was a similar multi-scientist interdisciplinary effort. A key summary finding of this report stated that 15 of the 24 essential ecosystem services evaluated were being degraded and/or used unsustainably. These included "fresh water, capture fisheries, air and water purification, and the regulation of regional and local climate, natural hazards, and pests." Their synthesis further noted the difficulty of assessing the full costs for human well-being of the loss and degradation of these ecosystem services, but they concluded that "the available evidence demonstrates that [the costs] are substantial and growing." Similar to the planetary boundaries report, the Assessment emphasized the interdependence between multiple ecosystem services and how actions to increase the supply of food, for example, can degrade other life support services. They further noted that the costs of degradation can be shifted between groups of people, at times unfairly, or left to future generations. An example of their many specific findings was that humans have accelerated species extinctions to rates 100-1000 times greater than normal rates observed in the fossil record. The study evaluated several scenarios for the future and concluded: “The challenge of reversing the degradation of ecosystems while meeting increasing demands for their services can be partially met under some scenarios that the MA considered, but these involve significant changes in policies, institutions, and practices that are not currently under way.”

For empirical evidence of a true ecological crisis we could also cite peak oil (Campbell 2005), water quality and quantity problems, human population, food production, and harmful toxins in the environment as well as many national and regional problems (e.g., chronic and systemic degradation of the Chesapeake Bay). We submit that current evidence is sufficient to decide that the global ecological crisis is real, serious, urgent, and best understood and addressed as *systemic*.

We thus ask how can we develop a systemic solution to the crisis? We also consider the related question of how can we in the life sciences lead the way to real and lasting solutions to the crisis?

The fact that we humans now threaten many essential aspects of our own environmental life support capacity at the planetary scale is a novel circumstance in history. We treat this situation as an opportunity to go back to the drawing board and address one of the classic “big questions” in science: What is life? When Schrodinger (1944) addressed this question in his classic text of the same title, perhaps he was inspired by the revolution in quantum physics. After having helped transform fundamental ideas in physics, he turned his attention to biology to see if he might likewise assist with revolutionary insights in that important field. Lovelock (1972) capitalized on a similarly unique historical moment and opportunity. When asked by NASA for assistance with detecting life on Mars, his attempt to go back to the drawing board to consider the fundamental nature of life led to his Gaia hypothesis and emphasis on the planetary scale of life’s organizational essence.

The current global ecological crisis provides another opportunity to review our fundamental understanding of life. This crisis suggests that humans in industrial societies may misunderstand the fundamental nature of life, or perhaps that the fundamental nature of life is changing.

What has been the prevailing life science paradigm during the centuries of development of our current systemic crisis? We see the key feature of this paradigm to be that it defines and identifies life with a unit such as the organism, cell, or individual in such a way *to separate life from its environment*. From this initial stance, we propose, the crux of our main environmental problem follows. Figure 1 depicts the large set of major environmental problems as surface symptoms of an underlying mindset that imagines life as separate from the Earth environment *implying that our scientific and cultural paradigm is the root cause of the systemic problem*. Figure 2-A shows generalized relationships between life and environment and how these are necessarily antagonistic given the current paradigm – life in its human, modern industrial form gains at the expense of the environment. This dilemma is related to the "tragedy of the commons" (Hardin 1968), in which social mindset and many narrowly self-serving individual actions conspire to degrade the quality of the shared environment.

At the center of Figure 1 we have a shared mental model, which for now we abbreviate as the "life = organism only" model, and this view of life is the operational norm in both life science and culture. Next, we see that from this paradigm, and by definition, life is separated from environment in mind (fundamental concepts and ideas) and action (motivations and behaviors as informed by the consensus understanding of life). After life is separated from environment, it follows that *the value of the environment is seen as less than value of life*. This may be linked to an inherent, primary and dominant urge for self-preservation of all living things, including humans. At the same time, based on this view of life that centers on organisms only, individuals are encouraged (and/or it is generally and culturally

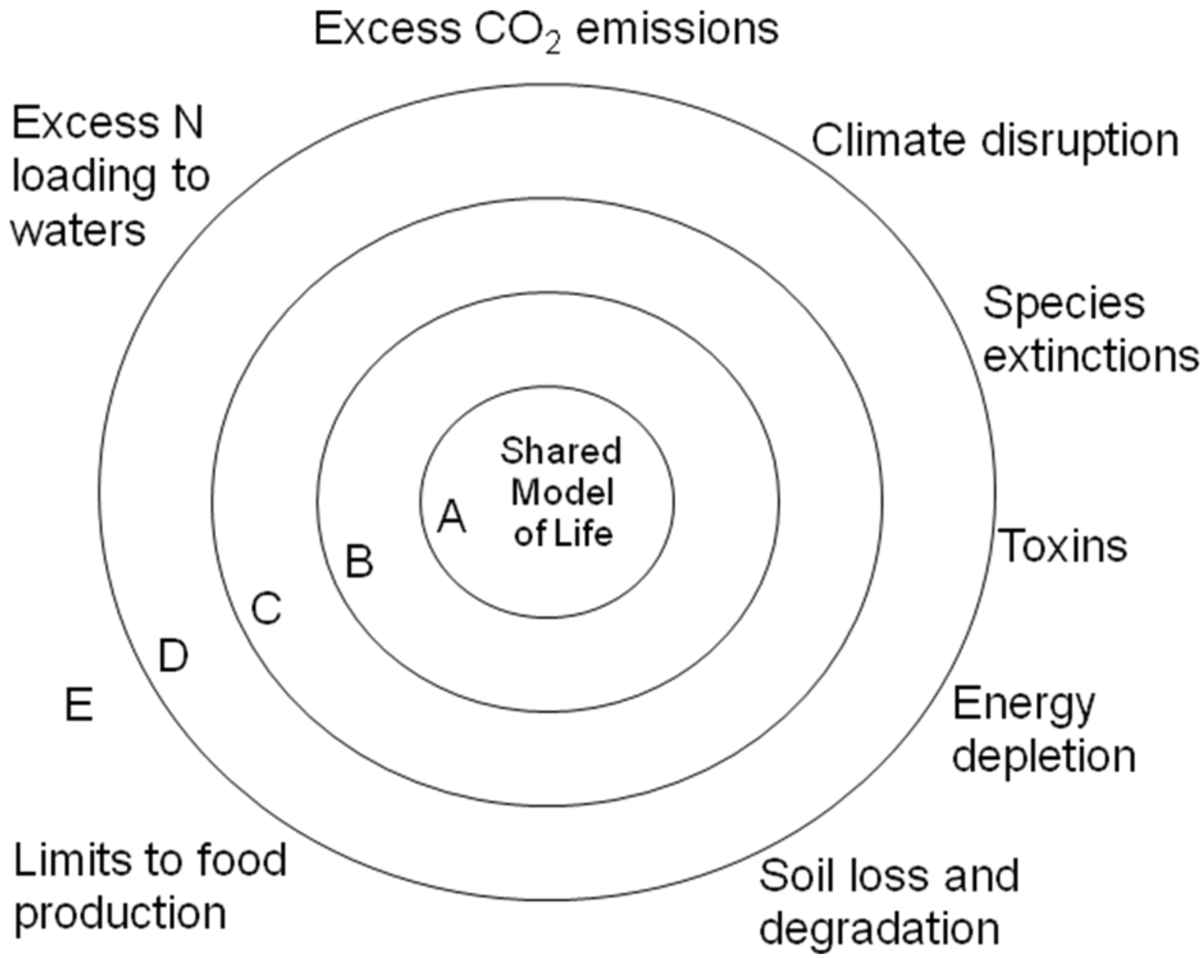

Figure 1. Superficial symptoms of global ecological crisis emanating from central systemic cause – shared mental model "life = organism only". Links proceed outward in stepwise fashion:

A. Mental model, "life = organism only", shared by science and most people in industrial culture
B. Life separated from environment in mind and action
C. Value of environment seen as less than value of life
D. Individuals act for self-interest primarily and compete for limited resources
E. Environment is consumed and degraded as manifest in many symptoms of ecological crisis

agreed) to act for narrow self-interest (interest of the individual or organism, and at times extending to close family) primarily and to compete for limited resources. Finally, as a result of all these links, the environment is consumed and degraded and we see this as manifest in many symptoms of ecological crisis. The key point is that if this hypothetical diagnosis of a root cause is correct, it can also lead the way to systemic solution.

Given our framing of the problem as an out-dated, insufficient and dysfunctional “life=organism only” paradigm, we can ask how did we get here? Patten (1982, p. 179) traced the history related to these ideas back to Darwin:

> Before Darwin (1859) environment was considered an organic whole. Everything in it made some contribution and had some meaning with respect to everything else. Darwin subscribed to this view, but his emphasis, and that of his followers, on the evolving organism struggling to survive, suppressed the exploration of holistic aspects of the origin of species that might have been developed. After Darwin, the organism came into great focus, first as a comparative anatomical entity, then later with physiological, cellular, molecular, behavioral and genetic detail. In contrast, the organism’s environment blurred through relative inattention into a fuzzy generality. The result was two distinct things (dualism), organism and environment, supplanting the original organism-environment whole (synergism).

We next propose to build a bridge across this resulting chasm of “dualism” in ways similar to efforts of Patten and other holistic science workers.

3.1 Framing the Solution

The hypothetical model and paradigm we propose here, and seek collaborative assistance to refine, fixes this fundamental antagonism. If we redefine life in such a way to integrate environmental processes, then we will likely have a more realistic idea (i.e., better objective fit to empirical data) of the fundamental nature of life, and we have the potential for the mutually beneficial relationship between life and environment depicted in Figure 2-B. To achieve such a win-win relationship, we assert the need for a new holistic, multi-model paradigm for life sciences that integrates two distinct and complementary life types, “discrete life” and “sustained life”, and three unit-models now used but not fully integrated: 1) the cell-organism-individual, 2) the community-ecosystem and 3) the biosphere.

To develop a solution along these lines we again adopt the holistic science strategy. In summary and synthesis, and as linked to the holistic assessment of the core problem above, the goal is a new situation in which:

The fundamental, net human-environment relationship is mutualistic or “win-win”.

To achieve this would be to fix the net human-environment relation so that it is no longer dysfunctional and suicidal. We want the fundamental human-environment relation to be mutually beneficial and mutually supportive so that humans live and gain (get resources, act, grow, develop, etc.) in such a way that also serves *to improve and enhance environmental quality over the long term* (see Figure 2-B).

In this holistic approach we define “win” in cases of both life and environment from a value basis relative to life. This biocentric approach to a basis for value and for right versus wrong follows Leopold (1949) who wrote, “A thing is right when it tends to aid the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise.” Powerful evidence exists for real win-win relations between life and environment. It has been generally true that over the long term the environment improves in terms of its quality of life support and carrying capacity for life as evidenced in the increased complexity of the genome, biochemistry, habitats, and interactions. Two major sets of evidence serve to illustrate this point. First, the oxygenated atmosphere of Earth is a unique characteristic compared to other planets (Lovelock 1988) and one which serves to make higher rates of

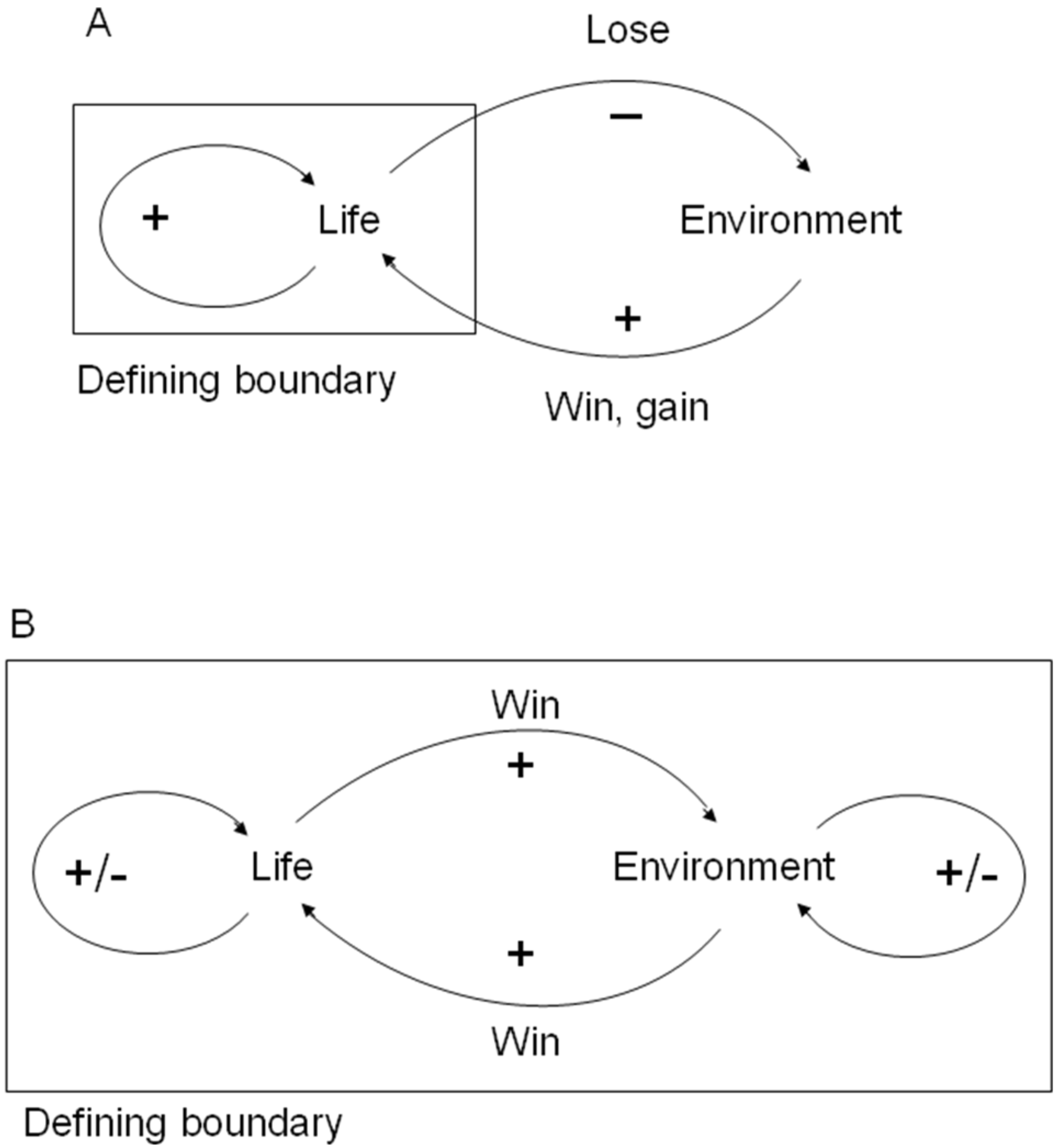

Figure 2. A. Current basic relationship between life and environment, both in terms of definition, paradigm and societal shared mental model, and in terms of resulting effects of applying the model everywhere. Life is imagined as separate from, different than and more important than the environment. Life (including human life) wins or gains at the expense of the environment. B. Alternative paradigm with life and environment integrated, with potential win-win relation.

energy and metabolism, and thus life forms like mammals, possible (Swenson 1989, Goerner 1999). Soils are a second major source of evidence that a win-win life-environment relation is possible (Van Breemen 1993). In forests and grasslands especially, soils naturally and spontaneously develop and increase in depth, complexity, fertility and functionality in ways that support greater diversity and resilience of living communities founded on those soils. We could also consider the generation and maintenance of species diversity, creation of those deposits that became fossil fuels, the ozone layer, and other aspects of biogeochemical cycles as evidence that a mutualistic and continually improving life-environment relation is not only possible, but is perhaps the norm when considering non-human or pre-industrial human life. Emphasizing the ubiquitous networks of relationships in ecosystems, Ulanowicz (2009) proposed that mutualism is ontologically prior to competition, which supports this view of an inherently mutualistic aspect to the original and fundamental nature of life.

3.2 Examining Assumptions and Changing Minds

Looking at Figure 2-A again, we see a simple diagram of life as separated from environment, and in which those adopting this view actualize an antagonistic win-lose relation (symbolized by +, -). In Figure 2-B we see the alternative, resulting from *a redrawn boundary that integrates life and environment*, and that could result in a mutualistic win-win relationship for humans and environment (symbolized by +, +). Again we could also link this generalized win-win scenario to multiple cases of real evidence such as Earth’s oxygen atmosphere, spontaneous development of soils and other real aspects of biophysical capacity for life that have improved over the long term. But how can we in the industrial human cultures get to such a win-win relationship now?

We propose that the first step is to “change our minds” in terms of the ways that we frame, view, understand, define, discuss, value and act to preserve and improve life. Patten (1982) gives a plausible history of how our current model of life as an organism separated from its environment arose. His account depicts this process as an historical accident by which a focus made to aid the study of life has gone too far. We could also say that this separation of life from environment was and is done “for purposes of discussion” only (T. Behan, personal communication). Looking at all evidence now, we must be clear that *separation of organism from environment is an abstraction*, a construction, a hypothetical starting point or assumption – it was and is always a subjective choice linked to a mental, imaginary or *fictional event*. We can confirm this and make this point rigorous simply and immediately. When we *actually* split life from environment – as if, for example, we used a real impervious boundary like a glass container to disconnect an organism from its environment – this real separation of life from environment disrupts essential (if invisible) relationships, destroys the life support of the organism and eventually results in death. As a thought experiment (and we propose this *only* as a thought experiment) this is most easily visualized by something like one of Priestley’s experiments linked to his study of air and oxygen – if we were to put a mouse (or human, or most any other type of animal) in a closed glass container, that organism would die as soon as its oxygen were depleted. Further exploration of such a real split of organism from environment shows that in most and likely all cases any organism separated and isolated will cease to live, because it has lost essential relationships entailing the capacity for sustained life (See the appendix for additional information on this thought experiment.)

A modification to this thought experiment illustrates the need to modify our basic paradigm of life. If we again use a glass container to create a closed environment, but if we include two functional forms – a complementary team of a plant and an animal – we would not destroy life or its necessary context-dependent relations by isolating this living subsystem, nor observe a single trajectory toward death.

Instead, if the O_2 and CO_2 gas exchanges of the plant and animal were matched, the team together could continue to live for a much longer time than either alone. Adding still more complexity, we could include inside the sealed container a full ecosystem with multiple functional types of species and soils. At this point the sub-units of life (organisms) inside this materially closed system could live, persist and self-sustain indefinitely (assuming sustained energy flow).

We use these simple thought experiments – all of which examine what happens when we actually separate life from environment – to make clear a distinction between the "*discrete life*" of cells, organisms and individuals and the "*sustained life*" of communities and ecosystems (and which we could extend to the biosphere). More discussion of complementary models of sustained and discrete life follows below.

In addition to expanding our basic concept of life from a discrete model only to dual discrete and sustained (continuous) life models, we propose the need to expand the mainstream single-scale, "life=organism only" model to a three-model multi-scale paradigm. Thus the three necessary "unit-models" of life are 1) the organism, 2) the community-ecosystem and 3) the biosphere. Each of these unit-models of life has unique properties many of which are fully essential to understanding life comprehensively. As a bona fide unit of life, the community-ecosystem displays plant-animal interdependence, biodiversity, co-evolution, food webs, local nitrogen cycling, indirect effects between species, and important mutualisms, among other essential properties which cannot be observed at, or fully explained by, life in its cell-organism-individual form. As a third true unit of life, the biosphere displays the oxygen atmosphere, soil formation, water and other major biogeochemical cycles, the ozone layer and other essential properties which also cannot be observed or fully explained by the cell-organism-individual form of life.

A variation on the "glass container" thought experiment above serves to test a core aspect of the hypothesis presented here. If one ever observed a single cell, organism, individual or even species surviving, reproducing and sustaining life long term *alone and in isolation from other life forms,* then that would falsify the hypothesis of fundamental life units at the community-ecosystem and biosphere scales. To our knowledge, no such observations exist. Instead, everywhere life is found it exists as integrated in community dynamics such as food webs and as interdependent with other life. In the absence of any such falsifying observations, Keller and Botkin (2008) and Morowitz (1992) provide corroboration for this view below.

3.3 Three Holistic Unit-models of Life

The next step toward synthesis is to recognize unique, fundamental properties of each "unit-model" of life. For the rest of this paper we simplify the name of the mainstream paradigm, which at times emphasizes cell, organisms or individuals, and call this the "organism" model. The organism is definitely a necessary unit-model of life, but we hypothesize it is not sufficient for either a best fit to real data and empirical observations or as a basis for the transformation needed to achieve environmental sustainability. The organism unit-model of life displays the usual list of special life properties such as metabolism, reproduction, sensing and acting on environmental stimuli, being made of cells, and containing information molecules such as DNA. It is interesting to note that while such life properties are widely familiar and logically associated with organismal life, not all textbooks, biologists, scientists or people agree on the specific descriptions of the essential life properties, or on which properties should be included in the list. See for example Lahav (1999) for a long list of diverse and often conflicting definitions and characterizations of life. Also compare the attributes of life emphasized in Campbell et al. (2008) and Ireland (2010), two introductory biological science textbooks.

Holistic models for life at each of the three main scales or levels of organization already exist thanks to the pioneering work and seminal contributions of Robert Ulanowicz and Bernard Patten (ecosystem), Robert Rosen (organism), and James Lovelock and Vladimir Vernadsky (biosphere). In each body of work, these focal units are shown to be unique and unfractionable "holons" (wholes that are also parts embedded and integrated into larger systems, from Koestler (1968)). A few highlights of the very large body of work each has contributed will help here. We present these three models starting with the ecosystem, since we see conceptual value in a focus on the ecosystem first, with synthesis effort to integrate one level below (organism) and one level above (biosphere) in the hierarchy.

3.3.1 Holistic Ecosystems

Robert Ulanowicz and Bernard Patten have contributed analytical methods (Ulanowicz 2004b, Patten 1978, 1981, 1982, Fath and Patten 1999), concepts, software (Ulanowicz 2002, Fath and Borrett 2006), empirical data, case studies and other corroborating work that demonstrates convincingly the essential need to understand life in its community-ecosystem mode. Ulanowicz' and Patten's work in ecological network analysis shows that ecosystems – as represented by food webs and the associated stocks and flows of energy, carbon, nitrogen and other biophysical currencies – are bona fide, holistic life entities. Their work also demonstrates that many of the essential life properties and characteristics exhibited by ecosystem networks are not observable at the organism scale of life.

A central idea of Ulanowicz (1986, 1997) is "autocatalysis", a term borrowed from chemistry that he uses to describe "self-enhancing" organization and behavior in ecosystem networks. His concept of autocatalysis in ecosystems overlaps with "indirect mutualism" and can most easily be visualized as a three-node system connected in a loop, in which each node (i.e., an organism, species or aggregated functional group) serves to enhance or increase the activity of the next node in the cycle, and in which nodes thus enhance their own activity as actions propagate around the loop and return to the start. Such positive feedback, autocatalytic loops are ubiquitous in cycles of energy and materials in food webs and of fundamental importance in understanding life. Loops in ecosystem networks all have the property of centripetality – and like centripetal force in physics they tend to pull inward toward the center of the loop. This special community-ecosystem level property provides better understanding of evolution, natural selection, competition and the striving to self-improvement of living systems. This systemic striving, Ulanowicz suggests, is missing from mainstream Darwinian Theory based on organisms, individuals and species, none of which are defined and modeled as having inherent positive feedback or autocatalytic loops.

In the philosophy of science, Ulanowicz has applied ecological network analysis (Ulanowicz 2004b) as part of a holistic scientific understanding of life. He also has argued strongly for a non-mechanistic approach to life science and suggests that "process ecology" provides a better basis for a paradigm of science than Newtonian mechanics or even Darwinian evolutionary theory. His process ecology (Ulanowicz 2006, p. 103):

> …depicts ecosystem development as arising out of at least two antagonistic trends via what is analogous to a dialectic: one direction is the entropic tendency towards disorganization and decay, which can involve singular events that defy quantification via probability theory. Opposing this ineluctable drift are self-entailing *configurations of processes* that engender positive feedback or autocatalysis, which in turn imparts structure and regularity to ecosystems.

Taken as a whole, his work forms an “ecological metaphysic” (Ulanowicz 1999) that he sees as general and robust enough to be valid for many scientific fields even beyond ecology. His parsimonious ecological metaphysic is based on three main tenets (Ulanowicz 2009): 1) systems are vulnerable to disruption by chance events, 2) a process, mediated by other processes, is capable of influencing itself, and 3) systems have different histories, and some aspects of unique histories are recorded in material configurations.

Ulanowicz provides many additional results, examples, observational evidence, case studies and analogies that serve to corroborate the view of community-ecosystem networks as bona fide, holistic, irreducible units of life. Ulanowicz and a co-author were also the first to show power law or Pareto distributions in the magnitudes of material flows in food webs (Ulanowicz and Wolff 1991). Power laws are widely viewed as signatures of self-organization, and thus these results support the view of ecosystems as holistic life entities with active agency. Ulanowicz has applied his theory and methods to ecosystems of the Chesapeake Bay (Baird and Ulanowicz 1989, Ulanowicz and Baird 1999) and Florida everglades (Bondavalli and Ulanowicz 1999), and has recently begun to apply network analysis to economic systems (Goerner et al. 2009, Ulanowicz et al. 2008).

Patten has developed holistic models of ecosystemic life via ecological network analysis and network environ analysis (1982, 1994; and Patten et al.1990, Patten and Jørgensen 1995, Fath et al. 2001). Similar to Ulanowicz (Ulanowicz and Puccia 1990, Bondavalli and Ulanowicz 1999, Ulanowicz 2009), the emphasis is on the indirect connections in networks and the distributed control or causation (Patten 1991, 1992, Fath and Patten 1998). At this level of organization, the analysis verifies that wholes are “greater than the sum of their parts”, and that systems are dominated by mutualistic interactions.

3.3.2 Holistic Organisms

Robert Rosen produced a challenging and original body of work, and one of his many major contributions was a holistic model of organismal life that he called the metabolism-repair model or (M, R)-system (e.g., Rosen 1958, Rosen 1991). In this model, which he developed and expressed via general systems theory, and mathematics using algebra and especially category theory, he associated "metabolism" with basic anabolic and catabolic processes in living cells. He added the generalized "repair" function, because he noted that all metabolic components – enzymes, for example – have a finite life-time and that after some period of operation these components cease to function and must be replaced or repaired (Rosen 1958). In perhaps his ultimate work, he used this model to address the question: What is life?, at times asserting a more relevant question to be: Why is an organism different than a machine? He answered these profound questions by showing how life, in the form of an organism, is "closed to efficient cause" unlike a machine (Rosen 1991). In essence this means that by their special internal relationships of metabolism and repair organisms are self-making or self-causing. See more discussion of efficient cause and how Rosen achieved this insightful result below.

Rosen saw life as organic, holistic, and inherently *unfractionable*. This unique feature is key in distinguishing life from machine (Rosen 2000, p. 291):

> …what makes the bird and the airplane so different in this case is again a matter of fractionability. The bird wing, for example, is an *unfractionable* combination of engine and airfoil. We cannot *physically* segregate these two functions into separate spatial structures. In the airplane, on the other hand, engine and airfoil *are* fractionable one from the other. They are fractionable because *that is how the airplane is built* – it is a consequence of its own ontology.
>
> This last observation is important. We generally construct things sequentially, by accretion, one structure at a time, one function at a time. That is how we build a machine; that is, in fact, *the only way we know how* to construct anything. Accordingly, we cannot build a bird; its ontology is different from that, and not equivalent to it. We *don't* build a bird wing, ultimately, because we *can't* build a bird wing; its nonfractionability removes it instantly from the province

> of things we can build.

This quote highlights a compatible approach to the effort here to understand life as a unified and unfractionable whole that we may better understand how to care for it and its necessary, integrated environment. Rosen also developed and championed ideas compatible with the paradigm of life proposed here, including a special definition of complexity (Rosen 2000), the modeling relation (Rosen 1985, 1991) and anticipation as a key capacity of all life (Rosen 1985).

Kercel (2003, 2007) has reviewed, critiqued, supported and further developed Rosen's work in areas related to ambiguity and the non-computability of complexity and life. For purposes here, we use Kercel's work on the impredicative logic and hyperset mathematics inherent in Rosen's metabolism-repair model and concept of life as closed to efficient cause. A brief description of essential ideas from Kercel is presented here, but see below for how these concepts are applied in the synthesis of a fully unified multi-model of life.

Kercel (2007) explained elegantly how the central unit-model of life of Rosen (1991) – in which life is equated with cell or organism, and the essential feature is closure to efficient cause – is best understood as a "closed loop hierarchy of containment". In Kercel's words (2007, p. 2370):

> Representation of 'closure to efficient cause' is demonstrated in *Rosen*'s metabolism-repair model, referred to as the (M,R)-system. The model consists of three algebraic maps. One map *represents* the efficient cause of metabolism in a cell. Another map *represents* the efficient cause of repair (the process that repairs damage to the metabolic process arising from environmental insult) in a cell. The third map *represents* the efficient cause of replication in a cell, *replication* being the process that repairs damage to the repair process (but has *nothing* to do with the cell making copies of itself).

And later (p. 2370):

> The Structure of the Closure. These three maps in the (M,R)-system each have a peculiar property. Each map has one of the other two as a member of its co-domain, and is itself a member of the co-domain of the remaining map. Thus the metabolism map is a member of the co-domain of the repair map, and the repair map is a member of the co-domain of the replication map…we can write phi ~ f ~ b ~ phi where the symbol '~' means entails. As can be seen, the three maps form a loop, but not just any loop. Note that the map does not merely entail the result; more restrictively it *contains* it. The maps form a loop of mutual containment. Map phi contains map f contains in map b contains map phi, *ad infinitum*…The important point is that the closed loop hierarchy of containment provides the distinguishing feature of the closure in the (M,R)-system. [Note the ~ symbol was used instead of the original symbol to simplify fonts.]

Kercel goes on to explain that this is the same structure as a three node *hyperset* in which any node is a member of one of the other nodes, and has the remaining node as a member of itself. A hyperset is a general type of set that may contain itself as a member. He also provides additional explanation for how containment relates to maps, and how Rosen used maps to represent generalized biological processes. A key aspect of this, according to Kercel (2007), was Rosen's treatment of maps as efficient causes that transform a set of material inputs (or more generally, a set of starting events) to a set of material outputs (or more generally, another set of resulting events). He also explains the necessity to note that any of the efficient causes, or maps, as Rosen used them, may appear as efficient causes from one perspective while appearing as some other kind of cause (i.e., another Aristotlean cause, such as formal or material cause; see more on the four causes of Aristotle below) from some other perspective. Thus the function or interpretation of each of Rosen's maps was inherently ambiguous, which Kercel explains is essential and to be expected.

Short of fully defining and integrating all of the hyperset theory and other terms employed by Kercel here, we can consider basic meanings of several. Where Kercel mentions "map", we can think of a formal representation of some life function or process. Kercel's "member of the co-domain" refers to either inputs to, or outputs from, some life function. Fuller explanation would require covering many additional technical details which we defer to future work. We do employ a general hyperset approach, and Kercel's closed loop hierarchy of containment, as a means to unify the three unit-models of this paper below.

3.3.3 Holistic Biosphere

James Lovelock and Vladimir Vernadsky are perhaps the most widely known scientists to have developed ideas of essential life properties at the biosphere scale thus supporting the need for a biospheric unit-model for life. In Lovelock's central novel idea – the Gaia hypothesis and later Gaia theory – he provided evidence and logic to demonstrate planetary relationships and processes by which the entire Earth shows self-regulatory behaviors and traits much like the self-regulatory behaviors of organisms. One articulation of this idea by Lovelock (1988) is that: "Living organisms and their material environment are tightly coupled. The coupled system is a superorganism, and as it evolves there emerges a new property, the ability to self-regulate climate and chemistry."

Lovelock's idea originated when he sought to explain the creation and maintenance of the oxygen-rich atmosphere of Earth, and the difference in atmospheric gas concentrations between Earth and neighboring planets. Atmospheres of Mars and Venus, for example, are more than 95% CO_2 with less than 0.15% oxygen, while Earth's atmosphere has 21% oxygen and only about 0.04% CO_2 (Lovelock 1988). Lovelock proposed that life was responsible for maintenance of the rare and far from equilibrium composition of Earth's atmosphere (Lovelock 1988, Boston 2008). Additional specific evidence came from Schwartzman and Volk (1989) who studied the increase in rock weathering rates in the presence of life and showed how it can help account for the drastic decline in atmospheric CO_2 since life arose on Earth (Boston 2008). For additional supporting evidence of Gaia theory Lovelock and others point to processes involving dimethyl sulfide (DMS) that provide feedback loops between organismal and planetary processes (Lovelock 1988, Harding 2006).

Lovelock's work on life's co-evolution with and role in regulating planetary processes borrowed from and supported prior ideas of Vernadsky, who most influenced the meaning of the term biosphere as it is used today (Vernadsky 1998). More recently Lekevicius (2006) has shown how "the Russian paradigm" of life, derived from Vernadsky and others, differs in fundamental ways relative to the mainstream view of life in the U.S., Europe and the West. For example, the Russian paradigm emphasizes the emergence of nutrient cycles on Earth as a key factor involved with the origin of life, while the Western paradigm does not (Lekevicius 2006, Table 1). In the U.S., work of Lotka (1925) was similarly holistic, although his emphasis on study of the entire Earth system with life and environment co-evolving largely has been ignored.

3.3.4 Holistic Life-Environment System

Borrowing from and seeking to integrate work of these and others works, Fiscus (2001, 2002) proposed an "ecosystemic life hypothesis" that was also compatible with the ecological origin of life scenario of H.T. Odum (1971). In this hypothesis, life likely arose as a set of coupled complementary processes of molecular string "composers" – analogous to autotrophic proto-organisms – and molecular string "decomposers" – analogous to heterotrophic proto-organisms. Odum (1971) described these pre-biotic chemical reactions as analogous to "production" and "respiration" and depicted them as arising prior to cells and organisms as aided by material cycles and photochemical reactions in "circulating seas". Toward applying such holistic models to social needs, Fiscus (2007, 2009) also published work demonstrating how natural food webs such as those in the Chesapeake Bay and Florida Everglades provide useful models and reference systems for the human food system, and how the functional energy and material organization of forests similarly provides an inspiring role model for truly sustainable human-environment systems.

3.4 Existing Multi-scale Conceptual Frameworks

To recap, we have made these major points so far:

1. We need a paradigm shift in our fundamental conception of life to solve the global ecological crisis and to explain better the observed symptoms and causes of this crisis.

2. The ideal new paradigm will provide the conceptual means to realize a mutualistic win-win relationship between humans and environment.

3. Simple, general and robust thought experiments demonstrate the need for two distinct and complementary types of life – discrete life and sustained life. These same thought experiments demonstrate how separation of life from environment is subjective, intentional, abstract and fictional – i.e., “for discussion purposes only”.

4. Pioneering work by Ulanowicz and Patten, Rosen and Lovelock and Vernadsky demonstrate holistic and essential life properties at the ecosystem, organism and biosphere scales, respectively, and we have ample empirical evidence that each of these is a unique, necessary and irreducible unit-model of life.

The last step then is to integrate the two types of life and the three unit-models of life into a coherent paradigm. A key goal of this process is to provide a means by which the three holistic unit-models of organism, ecosystem and biosphere can be *fully unified*. Once fully unified, it would no longer be possible to fraction or fragment life, or to study or attempt to manage life in terms of isolated or disconnected sub-units of life, or to conceive of life as separate from its necessary, life-supporting and co-evolving environment. This paradigm may be considered a *hyper-holistic multi-model of life*.

While this term may seem extreme or excessive, several similar and compatible ideas and schemes already exist. By highlighting the best existing schemes and their mutual compatibility, we cite evidence and logic to help a conceptual framework emerge with renewed holism and power for explanation, prediction, anticipation, and application to solve our current systemic crisis.

At least three corroborating views exist for the idea of two types of life, for the necessity of the distinction, and for individual definitions for "discrete life" and "sustained life". Morowitz (1992, p. 5) wrote: "…we recognize two approaches to defining life: one focuses on the properties of individual organisms and the other is much more global and ecological in character", and

> Sustained life is a property of an ecological system rather than a single organism or species. A one-species ecological system is never found. The carbon cycle requires at least one primary producer and a method of returning carbon to the CO_2 pool. A system of only herbivores would eventually die of starvation. A system of only primary producers would grind to a halt from CO_2 exhaustion unless autolysis or burning produced CO_2 at a sufficient rate, which does not appear to occur.

(Morowitz 1992, p. 54)

He went on to acknowledge that the origin of life can likewise be considered to involve key planetary processes including "protoecological cycles" and synergy between anabolic and catabolic functions.

Unfortunately, he may have diluted the power of his holistic and multi-scale framework when he wrote, in the same book, “All life is cellular in nature,” and later, “A cell is the most elementary unit that can sustain life.” Perhaps by not keeping the terminology, unit-models and associated properties related to sustaining life clear, and by other emphases such as titling his book “The Beginnings of Cellular Life”, Morowitz (1992) left the door open for the continuation of the cell-organism-individual unit-model as the primary basis for a single-type paradigm of life.

O’Neill et al. (1986) also addressed a special definition of sustained life and one challenge involved. They suggested that we "...define ecosystems as the smallest units that can sustain life in isolation from all but atmospheric surroundings. However, one is still left with the problem of specifying the area that should be included." Similarly, Keller and Botkin (2008, p. 66) wrote:

> To understand how life persists on Earth, we have to understand ecosystems. We tend to think about life in terms of individuals, because it is individuals that are alive. But sustaining life on Earth requires more than individuals or even single populations or species…Living things require 24 chemical elements, and these must cycle from the environment into organisms and back to the environment. Life also requires a flow of energy…Although alive, an individual cannot by itself maintain all the necessary chemical cycling or energy flow. Those processes are maintained by a group of individuals of various species and their non-living environment…Sustained life on Earth, then, is a characteristic of ecosystems, not of individual organisms or populations.

For this last statement linking sustained life to the necessary ecosystem unit-model and scale of organization, Keller and Botkin cite a Morowitz book from 1979, *Energy Flow in Biology*. Perhaps by clarifying or qualifying how “it is individuals that are alive” in this quote, this view can help communicate the two-type paradigm of life we propose.

We also have available several compatible schemes for identifying and describing multiple levels of life organization. Rowe (1961), and Kimmins (2004) citing Rowe, advocate a multi-scale framework for life with many strong points. Rowe (1961) proposed a series of hierarchical levels of life that included a common list with sub-cellular, cellular, organismal, population, community, and ecosystem levels, among others. Rowe went one step further and defined “true levels of biological integration” in an important way. This quote from Kimmins (2004, p. 29) explains Rowe’s idea well:

> Rowe (1961) defined a true level of biological integration as one that is “the total environment of all the levels of biological organization below, and a structural and functional component of the next level above.” He then noted that accurate prediction of events or conditions at any one level of biological organization can be made only on the basis of knowledge of the next true level of biological integration above. For example, the future development of a cell cannot be predicted merely from the tissue in which it is found or of the organ in which the tissue is located. Only by knowing the physiological condition of the entire organism can a reliable prediction be made concerning all aspects of any one cell in that organism. An organism is therefore the next true level of integration above a cell. The fate of an individual organism cannot be predicted on the basis of a knowledge of the population to which it belongs or from an understanding of the biotic components of the community to which that population belongs. Only on the basis of knowledge of the ecosystem will all the relevant antecedents that affect that individual be identified and considered and a reliable prediction concerning that individual be obtained. Ecosystem is the only true level of biological integration above the individual.

Rowe (1961) identified the cell, the organism and the ecosystem as three *true levels of biological integration*. And as described above he pointed out 1) how levels above serve as “*the total environment*” for all levels below, and 2) how context-specific knowledge of these hierarchical levels aids prediction of dynamics and development for any given level. While we disagree with some specifics in this scheme – and choose different focal unit-models, for example – the overall multi-scale and holistic perspective is highly compatible.

Work of Barrett et al. (1997) on “transcending processes and the levels-of-organization concept” is similarly multi-scale and holistic. Their idea was published in a journal section devoted to education (in BioScience), and they wrote: “In this article, we show how attention to transcending functions can provide a new integrative approach that can improve the critical-thinking and problem-solving skills necessary for dealing with long-term, large-scale problems.” They cite Rowe (1961) as described above, as well as O'Neill et al. (1986), and referring to the latter adopt the key term "hierarchy" thus: "A hierarchy is defined here as a graded series of compartments arranged from largest to smallest, but the order could be reversed to start with the lowest level of resolution." Their main hierarchy (their Figure 1) includes 11 levels starting with cells and ending with the ecosphere. They also identify seven transcending processes including energetics, evolution, development, diversity and more. They explain the importance of both vertical and horizontal efforts to understand such hierarchies and emphasize cells, organisms and ecological levels as three major focal compartments within their overall 11 level scheme (their Figure 2). Under a section they label "The tragedy of fragmentation", they wrote (Barrett et al. 1997, p. 531):

> In recent years, science has become so fragmented and specialized that the mismatch between traditional academic science disciplines and real-world problems has increased (Carter et al. 1990). Ever-increasing specialization is a recipe for sterility or error – sterility because the comprehensive picture may go unrecognized; error because the specialist may over-emphasize the significance of this or that datum in his or her own field (Cluge and Napier 1982)…Students also need to appreciate the natural integration of the biotic and abiotic universe.

And later (p. 531):

> Current modes of learning seldom emphasize that most basic principles, natural laws, mechanisms and concepts transcend all levels of organization, from cells to the ecosphere. Students are typically taught to consider only a limited range of organizational levels when addressing a particular process or mechanism. Thus, even after completing four years of undergraduate courses in any field of study, students often have great difficulty in comprehending both reductionist and holistic approaches (Barrett 1994, Odum 1977).

Despite such excellent work, and such clear and concise articulation of both the problem and a solution, and even the widespread teaching of such levels of organization in undergraduate biology (e.g., Campbell et al. 2008), "the tragedy of fragmentation" in science education, and the associated real-world multi-scale environmental crisis continue.

Additional compatible, holistic and multi-scale conceptual schemes exist, new ones appear regularly, and existing ones evolve and are refined continually. Holling and colleagues have developed "panarchy" as an especially robust and popular approach (Gunderson and Holling 2002). Holling et al. (2002) describe goals very similar to ours – better explanation of the intense global changes now observed, plus utility for adaptive human action in the face of such novel circumstances – and describe their proposed holistic theory thus:

> The theory that we develop must of necessity transcend boundaries of scale and discipline. It must be capable of organizing our understanding of economic, ecological and institutional systems. And it must explain situations where all three types of systems interact. The cross-scale, interdisciplinary, and dynamic nature of the theory has lead us to coin the term *panarchy* for it. Its essential focus is to rationalize the interplay between change and persistence, between the predictable and unpredictable. Thus, we drew upon the Greek god Pan to capture an image of unpredictable change and upon notions of hierarchies across scales to represent structures that sustain experiments, test results, and to allow adaptive evolution.

(Holling et al. 2002, p. 5)

Wimberley (2009) also presented his view of "nested ecology" that integrates the unique aspects of addressing "the place of humans in the ecological hierarchy" as well as a largest "mystery" level or "spiritual dimension" in which all known realms of life and environment exist, are nested and are even transcended.

4. Integrating Three Unit-models into a Single Multi-model

While each of these existing holistic multi-scale conceptual frameworks is excellent, all of them are mutually informing and corroborating, and all are being used, taught, researched and implemented to varying degrees and with many real benefits, we assert that something is still lacking. The inability of existing concepts to achieve a lasting and full unification of life, unification of life with environment, and solution to the global ecological crisis (by achieving a tangible win-win life-environment relation) may stem from the fact that most existing schemes are *linear* hierarchies. With the exception of panarchy theory, which depicts adaptive cycles at each level of hierarchy and across levels (Gunderson and Holling 2002), the schemes of Rowe (1961), Barrett et al. (1997) and others typically address influence between levels in either bottom-up or top-down linear fashion. Perhaps via limitations inherent in linear hierarchies, or some other issue, both of these schemes, as well as those of O'Neill et al. (1986) and Morowitz (1992), have not served to end or revise mainstream views of life types, levels or unit-models as fractionable and essentially independent. In other words, nothing inherent in any of these conceptual frameworks *explicitly prohibits fragmentation* – separation of life levels from each other, or separation of life from environment – and so disciplinary specializations that do both of these remain the dominant approach to both scientific understanding and human-environment problem solving (e.g., policy, regulations, management, etc.) Similarly, nothing in these schemes explicitly identifies, describes or explains how life achieves a win-win relation with environment, or how that could be achieved by humans.

To supply the missing elements, and in attempt to develop a modified holistic paradigm of life (*a hyper-holistic multi-model*), we seek to build in a fundamental unifying requirement – to explicitly prohibit fragmentation of essential unit-models of life and to explicitly prohibit fragmentation of life from environment. We then predict, from the initial stance of this unified paradigm, models and actions can follow that explain and provide means to actualize a systemic mutualistic life-environment relation. The initial progress achieved works with the three core unit-models proposed above: the organism, ecosystem, and biosphere. The synthesis involves three supporting steps: 1) to depict three semi-closed-loop material cycles, one associated with each unit-model of life, and all of which are also connected in a more fully closed-multi-cycle loop of material, 2) to associate strong and partial *causal closures* of three different types with each unit-model and show how all three are needed for the stronger causal closure of life as a unified whole, and 3) to propose a hyperset formalism for a closed loop hierarchy in which the three unit-models and life levels become fully unified from the origin of life onward.

Three material cycles fundamental to processes of life and environment often depicted and studied include the biogeochemical, biochemical and geochemical cycles (Kimmins 2004). These three material cycles correspond well to the ecosystem, organism and biosphere unit-models of life, respectively; and, they span multiple time and space scales, vary widely in the elements and compounds involved, and are spatially nested with smaller cycles inside larger cycles. These material cycles are perhaps most familiar to those in earth systems science, ecosystem ecology or biogeochemistry, but can and should be employed for understanding and managing life at all scales. Kimmins (2004, p. 72), in a textbook on forest ecology, provides important details about these material cycles, mainly in reference to carbon, nitrogen, phosphorus, potassium and calcium, but also relevant for all material elements necessary for life:

> The cycling of nutrients in ecosystems is complex. Some elements cycle predominantly between living organisms and the atmosphere, whereas others generally cycle between organisms and the soil. Some elements follow both pathways. There is also an internal cycle within plants and animals that acts to conserve nutrients within individual organisms. On the basis of these differences, the cyclic movements of elements in ecosystems can be assigned to one or more of three major types of cycles: the geochemical cycle, the biogeochemical cycle, and the biochemical or internal cycle.

He goes on to describe the geochemical cycles as those involving “exchanges of chemicals between ecosystems”, with examples of transport of nutrients in dust driven by wind and rain, transport of nutrients from land to oceans by streams, and CO_2 and O_2 gas movements over long distances (Kimmins 2004). Biogeochemical cycles involve exchanges of materials within ecosystems such as local nitrogen movements from soil into tree roots and back to soil via leaf litter fall, or potassium flux from soil into leaves of shrubs and back to soil via urine of grazing animals or predators. Biochemical or internal cycles involve the continual "redistribution of chemicals within individual organisms" (Kimmins 2004). This organismal cycle enables conservation of key elements, such as when plant nutrients are translocated from leaves before they fall, and is also familiar in essential physiological functions in animal circulatory systems. Kimmins (2004) also notes how all three of these material cycles are essential for and interdependent with another crucial functional aspect of ecology – energy flow.

We can view these three material cycles as fully unified via many perspectives. One way is by simply tracing the flow of any single atom involved in life process over an extended period of time. Tracing of elements on their journeys through life and environment can be and has been done quantitatively and scientifically, usually by use of radioactive or otherwise "labeled" atoms. Patten and Witkamp (1967) and Neal et al. (1967) reported early work with radioactive tracers as a means to understand structure, function and materials movement in ecosystems, and many other works exist as well. The general processes are basic enough that we can again use a thought experiment to easily convey the main idea, as inspired by Harding (2006), and the simple system diagram in Figure 3 can aid.

Imagine an atom of carbon fixed into plant sugar from the atmosphere during photosynthesis. This carbon atom bound into glucose might move to another area inside the same plant (along a portion of the internal biochemical cycle). The glucose might then be metabolized to provide energy for a physiological process in the plant, and the carbon atom might then be respired and emitted back into the atmosphere where it began. But it might also be that the original carbon atom eventually became incorporated into cellulose, and then entered the soil when that plant died. If so, then it could provide food for another living organism such as one of many leaf-eating insects. Then once embodied in the insect the carbon atom might move locally as the insect travels or disperses, or could be transformed on

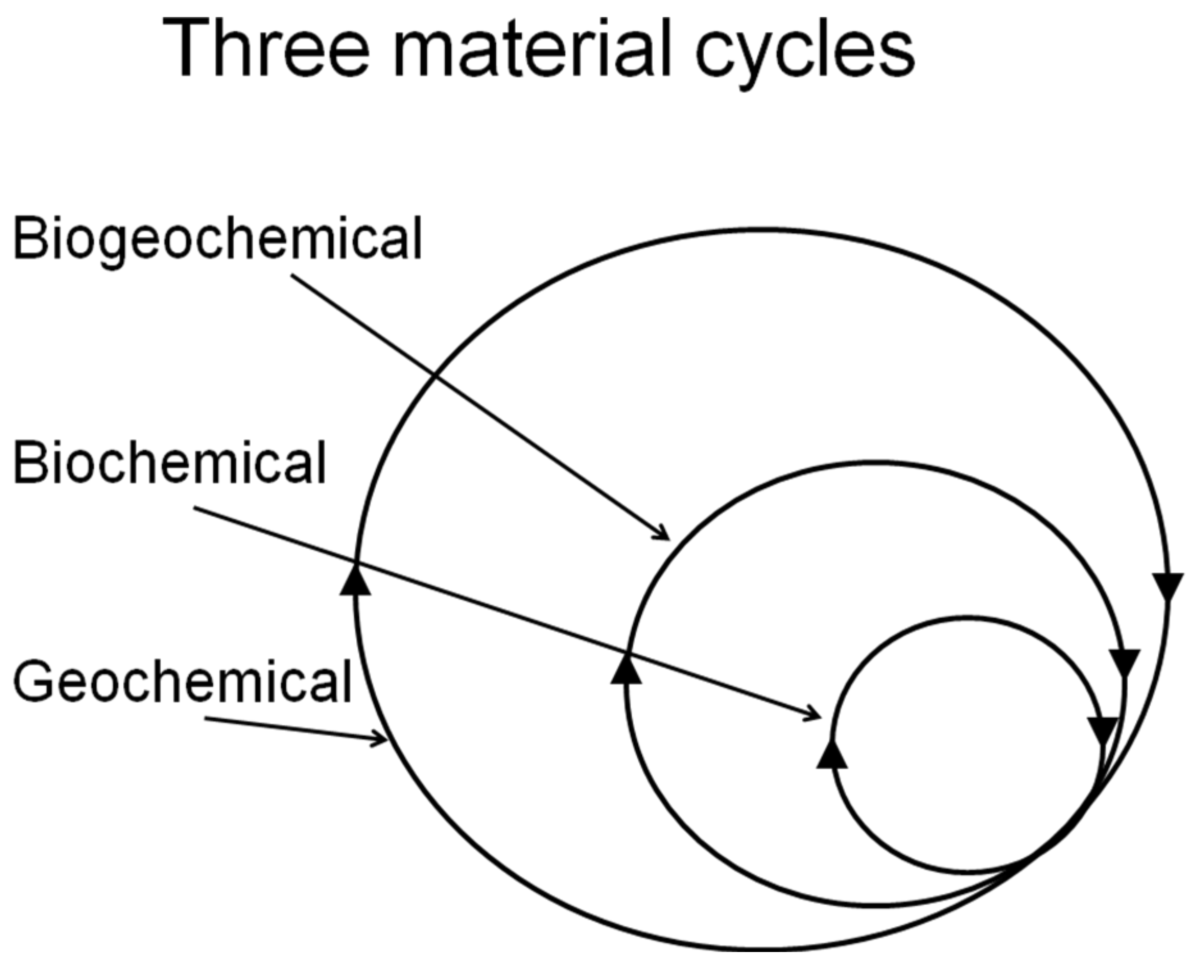

Figure 3. Three major material cycles associated with the three unit-models of life: biogeochemical (ecosystem), biochemical (organism) and geochemical (planetary biosphere).

up the food chain if eaten by some predator (either route part of a biogeochemical cycle). If the carbon atom became incorporated into the organic matter of the soil, then it might only return to the atmosphere much later (perhaps after hundreds or thousands of years), or it could be washed away and travel far downstream or even to the ocean via actions of rainfall, erosion and stream transport (part of a geochemical cycle). From this or any similar brief survey of the many possible pathways for our single carbon atom, it is clear that *all three major material cycles can and must be involved in any and all life processes*. And a similar result holds if we choose to trace the journey of oxygen, hydrogen, nitrogen, phosphorus, sulfur or any other element essential to life and provided by the environment. The continual turnover of elements in organisms is well-known and essential. The separation of the three major material cycles – much as for separation into the three associated unit-models of life – is again "for discussion purposes only". When we closely examine real systems (even by imaginary means) all three cycles are inextricably interwoven. An interesting recent example of work along these lines quantifies the degree by which ecological networks redistribute matter widely throughout all compartments – a phenomenon called "resource homogenization" (Borrett and Salas 2010, Fath and Patten 1999).

For the second basis for full unification of life, we shift now from material cycles to causality. One idea shared between material cycles and causality (and discussed above in reference to Rosen's holistic model of organismal life), thus providing a useful bridge concept, is *closure*. Aristotle famously developed four distinct types of causes, all of which he said are needed to provide comprehensive answer to any "why?" question. (Ulanowicz 2009, Rosen 1991). A fitting example is the case of a house as employed in Ulanowicz (2009). If we ask "Why does this house exist?" we could cite four different answers corresponding to the four distinct types of causality. The material cause of the house is identified with the bricks, mortar, lumber, nails, window glass and other material items essential to the existence of the house. The efficient cause of the house would be the builders who by their energy, action, intention, skill and motivation transform the materials into a house. The formal cause is best represented by the blueprint for the house – it is the plan and design that tells the builders in what form specifically the materials should be arranged. The fourth and last type is the final cause – the purpose, reason or function of the house – which is to provide shelter, home, a place to live for the inhabitants. Importantly, all four of these causes are need to answer questions of the form: Why does this house exist?

In this section, we present a way to integrate Aristotlean causality and the three major material cycles using the shared aspect of closure. We also introduce three distinct yet interdependent types of *relation* that aid the synthesis view of life as a unified whole. Table 1 links three generalized types of causal closures – closure to efficient cause, closure to material cause, and an intermediate form that is a blend, or partial closure, of both efficient and material causes – with three unit-models of life.

In this simple three-way distinction organisms are seen to be most closed for efficient cause in the sense of Rosen (1991). We can describe this as a characteristic self-making, self-causing or self-determining nature during a single organism's life span. The column noting "relations" associates this level with highly regulated and controlled processes of organismal biology and labels this the "life-life relation", as in strong structure-function relations internal to an organism (as linked to homeostasis, metabolism, growth, development, reproduction, etc.). Also in Table 1, biosphere is said to be closed to material cause. This is based on the general assumption of Earth as an approximately closed material system for which the internal cycling of finite materials is many orders of magnitude greater in mass or importance than matter that enters or leaves the planet. The biosphere is also associated with the geochemical cycles and with the "environment-environment relation". This set of relations, while still associated with life, can be thought of as those processes, dynamics and relationships that are strongly influenced by physical, chemical, geological and planetary factors. Finally, the ecosystem unit-model is classified as intermediate and having less strong and only partial closure for both efficient and material causes. The partial closures to efficient and material cause stem from the necessary organization in ecosystems with at least the two primary and interdependent functional types of organisms – autotrophic organisms such as photosynthetic plants, and heterotrophic organisms. Since these two are necessarily interdependent, they each at least partially participate in the efficient cause of the other. Heterotrophic organisms not only feed on plants to gain energy and nutrients, but also recycle the wastes of plants and the materials of their composition, thus providing a partial material causal closure for life at the ecosystem scale. Ecosystems are also logically associated with the “life-environment relation” such as those relations described in biogeochemical material cycles between organisms and soils, or between organisms and atmosphere, for example. Putting all three relations and forms of closure together results in life’s very high degree of self-causation that spans both efficient and material causes. Ulanowicz (2009) developed a similar set of links between causal closures and scales of organization and identified a closure of formal cause at the community-ecosystem scale linked to autocatalytic loops.

The third and final supporting step to a multi-model of life as a fully unified whole involves use of hypersets and the closed loop hierarchy of containment of Kercel (2007). While Kercel (2007) and Rosen (1991) invoked such ideas to explain life at the organism scale, we apply them to ecosystem and biospheric unit-models of life, and to the task of unifying all three unit-models. This scheme is qualitatively different from the existing multi-scale conceptual frameworks of Barrett et al. (1997) and Rowe (1961) in that *the relational hierarchy forms a closed loop*. The top level of the hierarchy links to the bottom level to represent a continuous organizational unity spanning all three unit-models seamlessly. We suggest this *relational closure* provides the basis to understand the life-environment system as a unified whole and then to manage this unified whole to achieve true environmental sustainability.

For this section we abbreviate the community-ecosystem unit with “ecosystem” and again abbreviate the cell-organism-individual unit with “organism”. We propose that something new is needed in addition to this typical linear, nested hierarchy that may be intuitive and conventional wisdom:

> The biosphere contains ecosystems which contain organisms

Or in terms of sets and borrowing Salthe’s (1985) notation for hierarchical systems:

> {biosphere{ecosystems{organisms}}}

We suggest the need for a closed loop hierarchy, which can be described in words:

> The biosphere contains ecosystems which contain organisms which contain the biosphere

Or:

> {biosphere{ecosystems{organisms{biosphere}}}}

This approach includes self-reference, which is handled well by the formalism of hypersets as explained by Kercel (2007). Again, a hyperset is a set that contains itself as a member. Hypersets are more general than regular sets, and they can be nested to varying depths and display context-dependent ambiguity in terms of what they represent (Kercel 2007). See below for a mention of how this can apply to trophic levels as well as the three life unit-models.

Kercel (2003, 2007) used hypersets to explain the resolution of the Liar's Paradox, to explain the unique aspects of M.C. Escher graphics, and as another means to understand Rosen's metabolism-repair model for life. In Kercel's work, ambiguity is of central importance. We also employ a form of ambiguity – or we could say a dual definition or context-dependent identity – for what "biosphere" means in the above closed loop hierarchy. If we take biosphere to mean the entire planetary environment on one hand (at the outermost level of the hierarchy) but also to mean any physical, chemical or molecular subset of that planetary environment on the other hand (at the innermost level of the hierarchy), then the closed loop hierarchy can make sense and be of great use. Organisms and cells do not contain the biosphere in terms of encompassing the entire planet inside their spatial boundaries. Instead, organisms and cells contain abiotic, physical-chemical, environmental elements and molecules necessary for life, each of which is of the same abiotic, physical-chemical nature as primary elements of the planetary environment.

It may be more clear to depict life using this closed loop hyperset hierarchy this way:

Life = {environment{ecosystems{organisms{environment}}}}

The benefits and implications of this holistic, self-referential multi-model are profound. Before discussion of these it may be helpful to consider this quote which is compatible with this model and, in particular, helps grasp the two inner most levels, organism and the environment inside it. This quote from Olomucki (1993, cited from Lahav 1999, p. 62) also helps illustrate the ambiguity and complexity issues well:

> When we attempt to define life, or living, we immediately come up against a fundamental and apparently irreducible paradox: living organisms are composed of inanimate molecules...Must we then say that 'life' is the interaction of all the inanimate components of this whole? In other words, that nothing is alive in a cell except the whole of it?

This holistic, self-referential multi-model based on hypersets is different than prior multi-model schemes, and has greater potential to help solve our systemic problem, since the relational closure *fully unifies all three life levels*. When viewed and modeled in this way, organisms, ecosystems and environment (or biosphere) are no longer separable or independent. The prior fragmentation - initially an analytical simplifying assumption that became reified when no synthetic counterpart process reversed it - is now repaired and explicitly prohibited going forward. Life is not and cannot be meaningfully identified or defined at any single scale. The life-environment system is inherently multi-scale, multi-model, *complex* in the sense of Rosen (requiring multiple models, containing impredicativities) and *unfractionable* in the sense of Rosen (none of the components can be understood, analyzed, or managed independently). This unfractionable nature of life is synonymous with the wholeness of "organic systems" of life as depicted by Ulanowicz (2001).

Organisms may indeed be highly self-defined and self-making during a single lifespan, but for life to persist long-term requires an inherent capacity to bring new self-making organisms into existence after they die. The additional, trans-organismal and self-referential functional relationship we might think of as the "self-making of the self-makers". The same fundamental concept of a closed loop hierarchy can be seen in food webs and trophic levels when we observe that "top level" predators die and their material bodies are recycled back through the "bottom level" soils and decomposers and pass through plants and around the biogeochemical cycle again, *ad infinitum*. It is important to note that this sustained life capacity is not fully explained by reproduction, since 1) it requires the abiotic, physical-chemical environment as an active participant, and 2) environment improves over time integrated with the process by which life continues (oxygen atmosphere, soils, etc.). Said another way, biological and organismal reproduction alone (by sexual, asexual or other process) does not ensure continuation of a species or of life as a unified whole.

This model, while simple to write down and express, has the potential to change everything about life – the definition of life, views of the origin of life, the shared cultural mental model of life, values, policies, actions and behaviors as they relate to life, living and sustainability (i.e., the ability to continue life). We believe this framework works objectively, in that it is compatible with and better explains empirical evidence and real observations, and it works subjectively, in that it holds potential to aid human change toward ideas and actions that better preserve and enhance life and its necessarily integral environmental context. And, as mentioned above, this model is also falsifiable by any observation of a single organism, species or functional type self-perpetuating in isolated relationship with the environment.

5. Implications, Applications and Future Potential

We summarize how this still formative paradigm of life has the potential to change everything with respect to how we conceive of life in formal systems or mental models, as well as with respect to our actions and how they impact the environment and life as a unified whole.

The hopes, speculations and predictions that follow all depend on much further development, testing, refinement and acceptance of the proposed multi-model paradigm of life. If these do occur, then this paradigm would change everything about life. Our definition of life would change from the standard dictionary and textbook versions that often cite the organism unit-model to one that is inherently multifaceted and complex, and requires at least the three unit-models of organism, ecosystem and biosphere at all times. This view of life also suggests unique approaches to frame the study of the origin of life. Instead of the strictly bottom-up and microscopic scenario – the origin of “cellular life” (Morowitz 1992) as most imagine it – the new paradigm suggests the need for a multi-scale perspective. The biospheric aspect of life plausibly played a key role, likely as related to the hydrological cycle. This cycle in basic systems terms is an interesting proto-type for life in the sense that two main phase transitions of water (evaporation and precipitation) and the interplay of solar radiation and Earth’s gravitation form a cycle that can run or sustain itself indefinitely. Another hypothetical aspect of the hydrological cycle we suggest worth exploring is the region of interface between freshwater runoff, estuarine dynamics and ocean circulation. A unique region called the estuarine turbidity maximum, an example of which exists in the Chesapeake Bay (North and Houde 2001), displays evocative characteristics at the place where freshwater running off from land meets salt water coming in the from the ocean. The interaction creates a stratification and boundary layer between the salt and fresh waters, has a high degree of mixing, circulation and resuspension of particles, and other features which could make it a candidate for the location of the origin of systemic life that embodies the intersection of major planetary, regional and microscopic dynamics, forces and creative elements involving water, land, atmosphere and ocean.

Beyond the definition and origin of life the multi-model paradigm of life also implies the need for changes to life science education, human values relative to life and environment, policies, behaviors, accounting methods and monitoring schemes. If this paradigm is to enable a systemic solution to the human-environment problem and enable true environmental sustainability, then the whole enterprise of life science education and the diffusion of life science knowledge and methods outward to influence industrial culture must change. We will need to revise biology textbooks, although in some cases only in fairly minor ways – most textbooks already describe life in terms of multiple levels of organization (e.g., Campbell et al. 2008, Ireland 2010), and these just need to be fully unified. We also have a need for new ways to assist students in experiencing the holistic nature of life. Our recommendation here is to develop a set of "interdependence chambers" – human-sized closed systems by which individuals could directly experience human interdependence with plants for the oxygen-carbon dioxide exchanges essential for every breath and every moment of human life. (See the appendix for a description of the basic design and operation of this experiential learning system). Large scale monitoring schemes like the ecological footprint, planetary boundaries effort and Millennium Assessment should be merged with social and economic metrics like the Genuine Progress Index (Cobb et al. 1995) and replace out-dated and misleading metrics like GDP and the Dow Jones Industrial Average as short-hand for whole-society trends, progress, health and well-being.

The tri-modal paradigm of life ostensibly provides a parsimonious, synthetic and robust explanation for the myriad and seemingly disconnected symptoms of environmental degradation we currently observe. This conceptual framework illuminates the key shared aspects unifying symptoms as diverse as fossil fuel energy depletion, climate disruption, accelerated species extinctions, nitrogen cycle disruption and similar signs of human-caused environmental degradation (see Figure 1). These unifying factors are 1) the shared core mental model of fragmented life and environment in science and culture in industrial societies and 2) the shared property of antagonistic or win-lose human-life-environment relationship where problems increase in number and worsen over time.

The multi-model paradigm of life also suggests several new predictions and possible avenues for experimental testing of these ideas. One very general prediction follows. First, if this paradigm is correct, then unless the holistic path it suggests (or some better approach able to explain the systemic cause and elucidate the systemic solution) is adopted, the paradigm predicts continued environmental degradation, loss of life support capacity and eventual widespread collapse of human populations, other species and essential ecosystem services. Conversely, if this paradigm is correct, and the holistic path it suggests (or some better approach) is adopted, then the paradigm predicts a reversal in environmental degradation and new trends and positive developments beneficial to restoration and maintenance of human populations, other species and essential ecosystem services.

Other scientific, more specific and testable predictions are possible, too. We only mention one example. The unified organism-ecosystem-biosphere paradigm of life is built on the obligate interdependence of the two main functional types – the autotrophs and heterotrophs. The paradigm also suggests that the environment always plays an integral role in life's structure, function, development, dynamics, systemic coherence and self-sustainability. One test of the necessary active role of the environment would be to work with a species that has the capacity for both autotrophy and heterotrophy, such as one of the dinoflagellates. If a single species of such mixotrophic dinoflagellate (Stoecker 1999) were placed in a suitable closed aquatic environment and thus isolated from all other species, then the multi-model paradigm suggests the species (or at least some significant proportion of the individuals, perhaps the majority) should evolve to specialize in one or the other functional type of feeding. The logic here is that if individuals or sub-species specialize into either autotrophic or heterotrophic forms, then this serves to segregate the spatial locations of the two essential ecological functions and by extension *requires that the aquatic environment play a continual mediating role between these two functional types*. This would establish a version of a three-node autocatalytic cycle (autotroph, heterotroph and environment) and provide the potential for positive feedback and indirect mutualism. Most importantly, if this development did occur, then it would demonstrate how life systems are able to grow and develop in ways that integrate the environment fully so that environmental carrying capacity can grow and develop in concert with the main living species.

These examples show that this holistic paradigm can and should be subject to scientific scrutiny and testing. We hope to participate in this and welcome any collaboration, or critique indicating problems, errors or flaws. Beyond this objective validity and potential for a good empirical fit with reality, the proposed paradigm holds the subjective potential to provide a basis for conscious evolution of humans and industrial society toward long term sustainability. To move in this direction – to begin to adopt and implement this holistic perspective as a critical element of solution to our systemic crisis – would be a drastic reversal of direction and reform of fundamental ideas and values. To aid this difficult and hopeful path forward, we compare and contrast two general cases.

Imagine two generalized scenarios for how this paradigm leads to a different outcome and better enables environmental sustainability. Consider our current land development routine. Typically and most generally, when land is developed we add people and we remove the natural systems that were there such as forests, prairies, meadows or deserts. At its most basic level, this current approach to development embodies and actualizes the current "life=organism only" model of life in which life is conceived and treated as separate from and of greater value than environment (including its life support and carrying capacity function). Another way to make this point of how we split human life from environmental life support in thought and action is that when we look at a parcel of land, we are able to think of it as occupied by <u>*either*</u> *humans* <u>*or*</u> *some natural system*. Looking at a region like the Chesapeake Bay watershed, we can see to what ends this development paradigm leads in terms of environmental quality and sustainability – the Bay and its watershed continue to suffer chronic and systemic environmental degradation. Now imagine that we instead operate from the proposed unified paradigm. In the revised scenario, we understand and treat life and environment as necessarily unified and interdependent. Thus, our "unit of development" shifts in systemic fashion – instead of a focus merely on units of land, or buildings, corporations or people, we must also integrate unit-models at the ecosystem and biosphere scales to actualize continual attention and value for energy flow, materials cycling, biodiversity, primary production, decomposition, soil formation, atmospheric regulation and other essential ecosystem services which all people need for life.

Working from a new fundamental world view that integrates life and environment, when we look at a parcel of land, we are NOT able to think of this unit of the environment as occupied by *either humans or some natural system but are only able to think of this unit as necessarily occupied by both humans and some natural environmental system*. Then, as development plays out on the landscape, if we plan to add people, the new paradigm informs the need to *add more life support capacity, not reduce it* – instead of being removed, the necessary complement to people must be grown and developed intentionally, in concert and in close coordination. This necessity may be addressed by adding life support capacity at local, regional, and/or global scales, but the holistic view of life makes the accounting and the implementation essential. Current policies which require no net loss of wetlands serve as example, but this policy must be extended to ensure no net loss, and even increase to match population growth, of the full suite of essential ecosystem services. As the figures show in highly simplified form, by redrawing the boundary to make the focal unit a *life-environment system*, and thereby elevating the value of environment to equal value with life, ideas, actions, behaviors and eventual real outcomes can all become win-win. This 180 degree course correction can also be described simply as requiring that accounting for carrying capacity and environmental life support functions get the same attention and priority as accounting for economic assets and related human individualistic variables.

While the solution sounds easy to say, and perhaps the win-win relation looks simple on paper in diagram form, the paradigm and the potential future it suggests also require a kind of mental maturity and wisdom associated with understanding a deeply complex, ambiguous and paradoxical nature of life. Not only must we have the wisdom to see the essential dynamic tension and complementary necessity of both life and environment, and not only must we resist the temptation for maximum short-term profit at the expense of the long-term life support of natural systems, at least two other deep dilemmas are implied by this holistic perspective. These dilemmas relate to 1) the way the paradigm integrates death of individuals as an inherent necessity of life, and 2) the need to embrace two seemingly opposite but likely both essential life modes - the “sustaining” and “transcending” (or growth-oriented) schools of thought or worldviews as related to the evidence of environmental problems, degradation and limitation. We reserve in-depth discussion of these topics for future work.

Goerner et al. (2009) write both eloquently and with rigorous scientific methods in network analysis. They convincingly show the dynamic tension between efficiency and flexibility that exists in both natural economies of food webs and ecosystems and human economies and financial systems. Their description of the “window of vitality” and quantitative means to define, measure and develop toward sustainability provide perhaps the most powerful example of the pragmatic application and long-term potential of the ideas presented here. If we follow their prescriptions, and value life as a unified whole integrated with environment, then we may eventually achieve the positive outcome depicted in Figure 4. In this revised figure, we see the concentric rings again, but now all the surface symptoms and individual environmental problems have been solved. If we fix our central paradigm of life, then we may also heal our world.

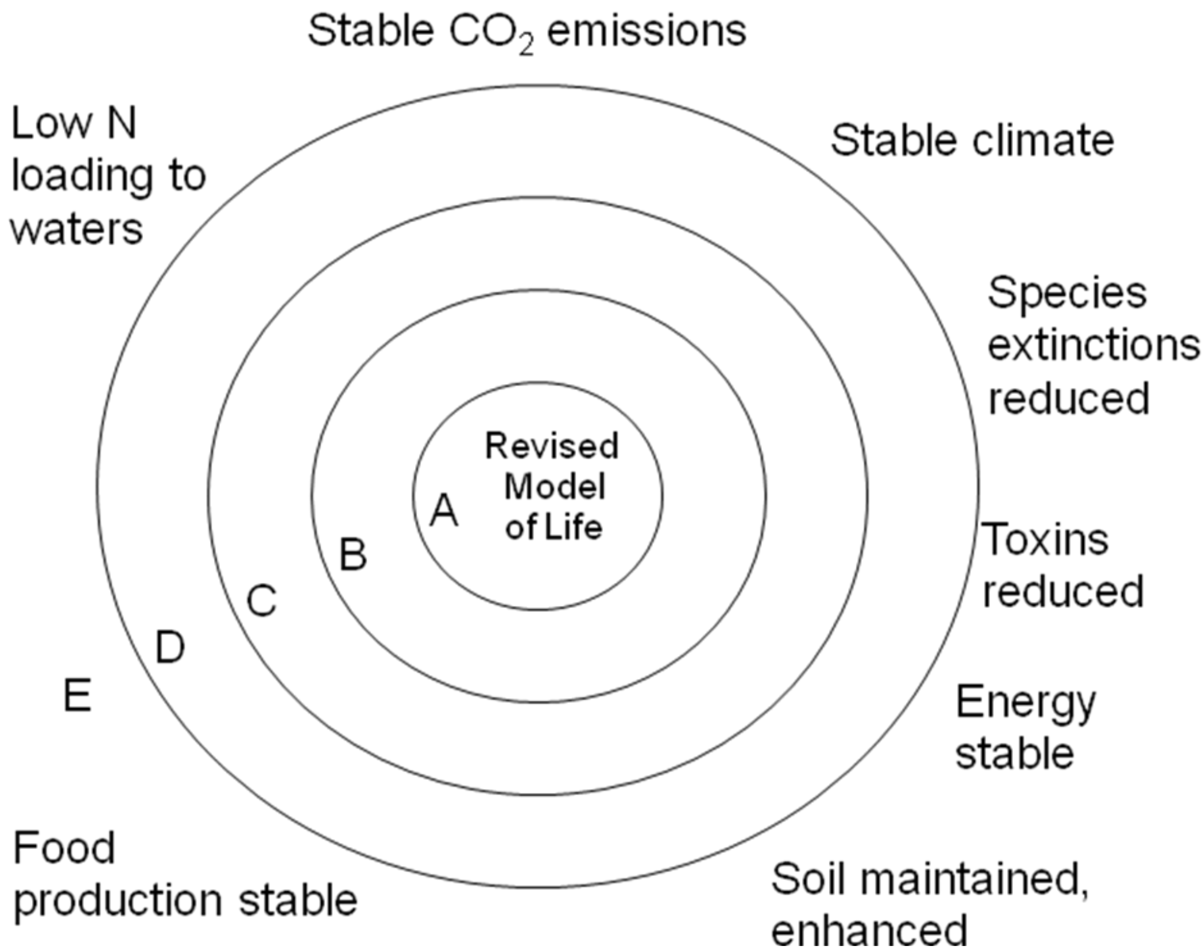

Figure 4. Characterization of positive surface manifestations, results of future global ecological quality as emanating from a central systemic cause – a revised holistic mental model of life. Links proceed outward in stepwise fashion:

A. Revised model, Life = {environment{ecosystems{organisms{environment}}}}
B. Life integrated with environment in mind and action
C. Value of environment seen as equal to value of life
D. Individuals act for redefined self-interest where self includes environmental carrying capacity
E. Environment is maintained and restored as manifest in many symptoms of ecological health

This paper represents an attempt to go back to the drawing board to consider that a holistic, multi-scale and relational conceptualization of the original and fundamental nature of life may prove better than the existing atomistic, cellular/organismal model, especially as applied to help solve our systemic environmental crisis. This work fails to incorporate or fairly acknowledge compatible works and ideas of many other authors. Much more should be said about the contributions of Goerner et al. (2008) on the science of sustainability, Patten's work on network enfolding, which he describes as "a powerful expression of systemic holism" (Patten 2006), Macy's work on mutual causality (Macy 1991) and ideas of the Great Turning (Macy 2011), Berry's Dream of the Earth (1988), Bateson's (1979) efforts to unify mind and nature, Henderson's (1913) depiction of the "fitness of the environment", Odum and Odum's (2001) synthesis of "a prosperous way down", Daly and Cobb's (1989) efforts to create a relational and ecological economics, and the holistic life-environment story of "The Lives of a Cell" by Thomas (1974), among many others.

This project is motivated by the sense that the biophysical, ecological and environmental suite of problems now occurring and in many cases worsening requires a fundamental rethinking of major ideas of life and environment. Another way to describe the central paradox of our current times is the following mismatch between:

1. The widespread belief shared by biological sciences and economics that acting solely to better oneself – either the individual human or the individual organism – results in betterment for both self and the greater community of life.

2. The striking evidence that this paradigm, as we see it carried to logical conclusion or full expression in modern industrial culture, is associated with degradation of essential life support capacities for the planet that now endanger both collective and individual forms of life.

The new proposed model resolves this apparent paradox and provides a missing synthesis. The paradigm resolves the apparent paradox of life's individuality, autonomy and organismal discreteness on the one hand with its pervasive unity, interdependence and integration with the Earth environment on the other. It recognizes and validates past work and sub-field specialization in life science at the scales at or near the organism, ecosystem and biosphere while also providing a new logical, mathematical, rigorous and testable model for how all these can be seen as interdependent and complexly nested subsets of life-environment as a unified whole.

We propose that science and society need just such a coherent unification of life – a newly modified answer to a classic big question: What is life? – to match the scale, gravity and urgency of the global ecological crisis. If we could develop, test, validate and build consensus on such a unifying life paradigm within science that renewed understanding of life, then this could help inform new and more effective responses to environmental problems. The holistic and systemic nature of the proposed paradigm also matches the systemic nature of the problems and crises we see. As such, it is uniquely capable to provide the knowledge needed to inform actions which address the root cause of our crisis and thus have the greatest potential for true and long-term success.

The conceptual framework of life-environment as a unified whole provides a new sense of place for humans – not only are we each independent and autonomous wholes, but we are also inseparable parts in a larger living whole that includes all other life and the environmental systems of Earth. This paradigm provides a new clarity to the planetary and ecosystem networks of relationship that provide the system and context in which human beings can be brought into material existence. The same holistic model depicts and adds new meaning to how an individual's death similarly entails humans being taken out of material existence. As one life ends, the materials of which we are made return to the great cycle of life and the biogeochemical cycles of the planet. While these ideas are couched in terms of material flows and transformations, they clearly invoke and influence spiritual considerations as well. This richness of meaning is compatible with work of Robert Ulanowicz who has shown how ecology provides a logical middle ground between scientific and religious worldviews (Ulanowicz 2004a).

If successful, then the revised paradigm of life science and consequent action would provide that ideal result sought in point #1 above - that independent actions of billions of individuals can in fact scale up to results that are beneficial to both the many (all individuals) and the one (life as a unified whole) over the long term, including the preservation and enhancement of environmental quality and life support capacity.

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Table 1.

Associations of cycles, relation types, unit-models of life, and causal closures.

Relation	**Life unit-model**	**Causal closure**	**Material cycle**
environment-environment	Biosphere	strongest closure to material cause	Geochemical
life-environment	Ecosystem	partial closure to material cause, partial closure to efficient cause	Biogeochemical
life-life	Organism	strongest closure to efficient cause	Biochemical

Note: The cycles are the three major material cycles described in the text and by Kimmins (2004).

Appendix – Experiential learning system for direct experience of human interdependence with plants and other life.

The following briefly describes an idea to build closed systems to aid in direct experience of human interdependence with plants and other life forms, and to demonstrate and illustrate the essential difference between “discrete life” and “sustained life”.

The systems will be two glass or plexi-glass chambers, each large enough for a human to get inside and either stand or sit comfortably.

One chamber will have nothing inside, except perhaps for some small equipment to enable monitoring of O_2 and CO_2 concentrations inside the system. When a human enters, and the chamber is sealed so as to be air-tight and to cut off the system from any gas exchange, that individual human will eventually deplete his/her oxygen supply. If no more oxygen is added, that human will die. Thus to seal off the chamber is to cut the essential relationship of organism to its environmental life support capacity. This demonstrates the concept of “discrete life” and the insufficiency of “organism” as a single unit or unit-model for understanding life comprehensively. It shows how our conventional concept of organism as a separate entity from environment is an abstraction or simplifying assumption made “for discussion purposes only” (T. Behan, personal communication). See main text of article for additional explanation.

The other chamber includes a selection of green plants. When a human enters, and the chamber is sealed off, the oxygen will be supplied continually and carbon dioxide recycled continually. The human is in no immediate danger of running out of oxygen, and could stay in this sealed chamber indefinitely (assuming a good match of plant capacity to human capacity for gas exchange needs and continued sunlight entering). This system has a greater or more open-ended capacity for “sustained life”. It can operate or “live” much longer.

Many details and design issues remain to be developed. Sensors and monitors showing the concentrations of O_2 and CO_2 inside each chamber would add to the experience for both a person inside a chamber and those observing outside. Safety protocols will be developed to ensure no one can be trapped inside a chamber accidentally.

Two web links describe work and issues that are closely related.

The first is quite the elaborate and technical experiment; this site includes a short video describing it (with several ads coming first). This work has much overlap with the idea and plan for educational interdependence chambers:

http://www.5min.com/Video/The-Interdependence-of-Man-and-Plant-in-Space-Training-311434238

The second one is an educational lesson plan for how to make a system to enable a very long term space mission. This examines a very similar set of issues about life in its ecosystemic and “sustained life” forms and the necessary interdependence of humans and other functional types of organisms.

http://www.sciencenetlinks.com/lessons.php?DocID=295 (this link now dead…seeking lesson plan)

The following references have been helpful in developing the idea for “interdependence chambers” and will be used for their future development.

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