Chapter 5

INTRODUCTION TO ECOLOGY: ECOLOGICAL SYSTEMS

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I. Defining the Ecology Driver

The classical definition of Environment is "everything outside of us." The environment is the totality of our surroundings, including other organisms, the non-living components of our world and universe, and the social/cultural milieu within which we function. For our purposes here, the concept of environment is too broad. What we are really looking at as a driving or determining force -- as an apex in our sustainable development triangle -- are the ecological systems that serve as a foundation for all life on Earth and for the social systems that mankind has developed and wants to maintain. Further, whereas the term environment is a socio-cultural construct that suffers and benefits from a certain degree of ambiguity and, therefore flexibility of definition and application, the term ecosystem is a scientific concept that defines a complex of physical-chemical-biological processes that operate on a local or regional scale.

> **Ecosystem** - Any unit including all of the organisms in a given area interacting with the physical environment so that a flow of energy leads to a clearly defined trophic structure, biotic diversity, and material cycles within the system (Odum, 1971).

While the term "ecosystem" was coined by A. G. Tansley in 1935, the concept -- that of our relationship to other animals, plants, the soil, the wind, the sun -- is much older, going back to the earliest writings of human societies around the world. Ancient societies were in intimate contact with nature and much of our mythology and ritual is rooted in early man's attempt to make sense of, and thereby control, the fearsome natural world. As cultures evolved, this concern for our relationships with other living and non-living things became imbedded in religious thinking and writing (White, 1967, Campbell, 1972).

For most of human history, mankind, lacking knowledge and adequate tools, had to accept and live with the forces of nature. Until very recently, human numbers were so low in most parts of the world, that natural carrying capacities were not threatened. All of that began to change about four hundred years ago with the advent of the industrial revolution. In an instant in ecological time, human society learned to tap the stored wealth of minerals and energy, developing techniques for garnering mineral wealth and ecological productivity, past and present, for immediate human needs. This new knowledge and technique also enabled mankind to shed the severe constraints that had kept population levels well within carrying capacities for millennia. The danger that these "achievements" posed for the future were recognized as early as the mid-nineteenth century by thinkers such as Malthus who warned us of impending food shortages and George Perkins Marsh, who in 1864 looked at the decline of ancient civilizations and warned that we could face the same fate unless we learned to live within the natural system -- a distinctly ecological view. Seventy years later, and nearly sixty years ago, Aldo Leopold again lamented our exploitive relationship with what we now call ecosystems, noting that "Christianity tries to integrate the individual to society, democracy to integrate social organization to the individual. There is yet no ethic dealing with man's relation to the land" which is "still strictly economic, entailing privileges but not responsibilities (Sand County Almanac, as reported in Wiens, 1972)."

If we are to succeed where past civilizations have failed, if we are to develop a truly sustainable society or collection of societies, we must recognize that we are part of a greater system of forces and processes, a system that has evolved as the Earth has matured, incorporating complex mechanisms for both stability and change, a system in which energy and materials interact in complex but largely predictable ways governed by intricate and delicate information systems, a system with tremendous diversity and biotic potential, a system that is adaptable and resilient, but a system with limits -- absolute limits. If we are to succeed, we must develop cultural, social, economic, and political institutions that are founded on a recognition of our ecological heritage and dependence, on an understanding of the structure and function of ecological systems, and on an understanding that stable, functional ecosystems are essential to our well-being and the survival of our social systems.

The Ecology apex to our sustainable development triangle carries with it some very distinct attributes. We might call these Ecological Paradigms:

1. **Ecosystems are materially finite and the Earth is essentially a CLOSED system in a "materials" sense.**

   With the exception of minute inputs from and losses to outer space, we are endowed with a finite supply of materials. Within ecosystems, materials cycle in and out of living organisms, and the productivity of these organisms is LIMITED by the finite availability of critical materials (nutrients). A deficiency in a single nutrient is often sufficient to reduce or stop growth. These limits are real and are evident in ecosystems throughout the world, especially where human abuse of the ecosystem has depleted nutrients and/or damaged the cycling system; many nutrient cycles are dependent on microorganisms that transform minerals from one form to another. It is important also to understand that the impact of abuse is not always gradual. Some ecosystem processes have thresholds of abuse, below which they may appear asymptomatic. Once the critical threshold his surpassed, however, an irreversible downward spiral or plunge of degradation occurs.

2. **Ecosystems are OPEN in an "energy" sense.**

   Energy flows through ecosystems. As it passes through the ecosystem it does work, creating biomass in plants, animals, and microorganisms and providing chemical energy that these organisms can use for maintenance. At each step it is degraded according to the Second Law of Thermodynamics leaving less available for subsequent links in the food chain. Some energy is stored for shorter (wood) or longer (coal, oil, gas) periods of time. Ultimately at a global scale, however, inputs and outputs of energy are roughly in balance. Were this not so, the earth would either heat up or cool down, as can happen with the greenhouse effect or glaciation. Further, because of the Second Law, no system can long endure without an external source of energy. This certainly has direct implications for energy policy planning in human societies.

   The earth is essentially a huge heat engine with energy being supplied largely by the Sun and the distribution of both chemical energy and heat being controlled on Earth by a complex set of information processes embodied in functional ecosystems. Damage to these systems can be destabilizing, resulting in alteration of the energy distribution in the biosphere and the patterns of global heat dissipation. The result can be an increase in the frequency and severity and a decrease in the predictability of storms.

3. **Because of limits of energy and materials, ecosystems have finite carrying capacities.**

A given ecosystem, landscape, or region receives only a certain amount of solar energy each day and is endowed with only a finite supply of materials. Therefore, ecosystems will support only a certain amount of biological productivity at any one time. The carrying capacity differs considerably from ecosystem to ecosystem and from one type of organism to another. There is strong evidence that human population has exceeded the carrying capacity in many ecosystems, especially those fragile or marginal-lands ecosystems in the tropics and semi-tropics. The evidence lies in the degradation of the vegetation and soil in these ecosystems. Human pressure places demands on these ecosystems that go beyond their ability to provide. More is taken from the land than is put back in, outputs exceed inputs, nutrients are depleted, and the land becomes increasingly nonproductive. At some point in this downward spiral the process becomes essentially irreversible; desertification is the result. Today more than 600 million of the world's poor live under such conditions and the numbers are growing (Durning, 1989).

4. **Ecosystems are highly connected and integrated. Actions occurring in one part may affect other parts or other ecosystems.**

There is an favorite saying among environmentalists that in ecosystems everything is connected to everything else -- that you cannot pick a flower without disturbing a star. While this is certainly an extreme overstatement, it is true that ecosystems are highly complex and integrated. An ecosystem is the extant manifestation of ecological conditions and biotic potential on a site with thousands of organisms adapted to prevailing conditions carrying out millions of interactions with each other and with the abiotic components of the system. Processes in one ecosystem affect adjacent ecosystems and in many cases such impacts can be carried afar on air and water currents, or in our modern world on economic or political currents.

As mention above, energy is distributed throughout the world via climatic flows and cycles. Rivers and ocean currents and air sheds, streams, and flows transport energy, materials, and information -- good and bad. Migration and dispersal distribute genetic potential. Complex feedback mechanisms enable organisms to respond to changes in their habitat.

Ecosystems are also connected and integrated by the hand of man. Economic forces reflecting or controlling supply and demand in one part of the world are increasingly having impacts on distant ecosystems. Political currents and events have similar impacts; decisions in one part of the world impacting ecosystems half a world away.

5. **Ecosystems operate on a time scale of tens to thousands of years.**

Ecosystems undisturbed by man have the appearance of permanence, and in a certain dynamic sense this appearance reflects a degree of reality -- at least in the context of human life times. Natural ecosystems have evolved complex information mechanisms that provide for both stability and change, stability over the short run and change over the long run. These information systems have evolved in response to fluctuations in local and regional climate that occur in cycles ranging from a few to several thousands of years. Genetic potential, diversity, dispersal mechanisms, storage, are a few examples of such mechanisms that insure that biotic communities can adapt to changing environmental conditions.

Ecosystems are also susceptible and have adapted to longer-term geologic processes -- most notably erosion. Erosion is a natural physical process that is slowed by biotic communities, primarily the plant components, which hold soil in place and contribute organic matter to replace that lost to erosion, or, in areas of low erosion potential to actually build soil. Human activities, including -- or especially -- agriculture, accelerate natural geologic processes by altering -- simplifying -- the information systems on a piece of land.

Natural ecosystem processes are long term; building one inch of soil can take several hundred years on moderate to good sites -- on marginal sites or those seriously degraded by man, the process may take a millennium or more. The greater the damage, the longer will be the natural recovery time. At some point, damage can exceed some invisible threshold beyond which the natural ecosystems, deprived of basic resources required for productivity and of critical information systems necessary to mediate the recovery process, cannot recover on their own.

In an ecological sense SUSTAINABLE means maintaining the resource base and the information systems on a site for indefinite periods of time. To speak of implementing agricultural systems that would insure that the soil will last for at least 200 years is ecologically unsound -- and I would think it would be socially unacceptable also. How would we feel about our forefathers if they had put such a plan into effect in 1776?

6. **Stable Ecosystems provide essential services to human societies. They are predictable, flexible, and largely self controlled.**

Down through history, societies throughout the world have benefitted from services provided largely free by their local and regional environment. Such services as clean water and clean air, water storage and infiltration, fuel, fiber, food, waste purification are just a few of the more obvious benefits. Perhaps the most important services that healthy ecosystems have provided to human societies are predictability, flexibility and control. Agriculture and most other endeavors essential to modern man depend on the predictability of the environment, on the flexibility that provides for choice in the use of land, and on the internal controls that hold ecosystems together. As human societies have grown in numbers and exploitative capacity, man has tried to enhance the services extractable from the environment by reapportioning ecosystem materials, energy, and information to generate products useful to himself. In an ecological sense, this mean reallocating energy and resources away from maintenance into production -- production of products that man needs, products that are increasingly removed from the land, i.e., less stem and more grain. In so altering his natural environment, man has replaced systems that have evolved in place on a site and are to a large extent self maintaining with systems that require significant help from man to survive even one season or one life cycle. Systems that can no longer maintain themselves will degrade and lose the capability to provide the services that they once could. This process is occurring throughout the world today, especially in tropical regions.

Social institutions and mechanisms must be developed that recognize and place real value on the essential services that stable ecosystems provide.

7. **Ecosystems comprise things (animals, plants, soil, etc.) and processes (nutrient and energy transformations, productivity, decomposition, etc.). Stability in these systems is more dependent upon processes than on things.**

   Conservation thinking over the past hundred years has focused on commodities and species as the things that need to be protected and preserved. In our current thinking about sustainable development, we have also tended to focus on resources and products such as wood, fisheries, crops, etc. This has led to the creation of artificial systems such as plantations, fish ponds, and green revolution crop systems that provide society with essential commodities. This focus on the things, especially those things that man needs or wants, has distracted us from what is really important in ecosystems -- the processes. It is the processes that determine the stability of the system. The species that grow in the system can vary as long as all of the Jobs required by the system, energy capture, nutrient cycling, decomposition and regeneration, waste removal or purification, etc., get done. It is also the processes in an ecosystem that are responsible for the non-commodity services that these ecosystems provide for human societies. It is certainly a reality that for the foreseeable future. We will have to depend on such human artifacts as plantations, fish ponds, and high intensity agriculture to support human population, but in planning for and designing such artificial systems, we must strive to emulate natural systems -- in the sense of processes -- as much as possible. We should also provide economic incentives for protection of critical natural systems such as watersheds, recharge areas, and waste sinks.

8. **Ecological systems are arrayed in a complex mosaic of subsystems that taken together in a region make up a landscape. Within a regional landscape, energy, materials and information are exchanged among landscape units. Stability of the landscape over long periods of time allows for spatial and temporal variation and fluctuation in stability among its parts. At this scale, it is mosaic stability that is important.**

   Perhaps the most productive way of addressing sustainable development is to focus on the landscape as the functional unit. A landscape can be defined at any level of scale from a small hill side to a full continent. Within a landscape, we can identify sub units with specific ecological characteristics. These are called landscape units and may, if so defined, correspond to ecosystems or land-use units. A landscape ecologist studies the ecological structure and function of defined landscape units and how these units interact ecologically with adjacent and distant units within the greater landscape. At any one place or time, units will have different states determined by local conditions, natural or artificial. Some units may be in a state of growth (accumulation of materials, energy, and information) while others may be in a state of decline (losing materials, energy, and information). Few will, at any instant, be in a state of stasis; stasis being rare in nature. Thus, there is constant change within the landscape with materials, energy, and information being moved about within the system. The landscape will remain stable as long as the mosaic is stable.

Part of the challenge for ecologists and others concerned with sustainability, is to define the landscape at a scale that will provide for mosaic stability in the face of fluctuating states in the various landscape units. Only by defining the system at the appropriate scale can we develop economic and political systems that accurately reflect resource economies and choices available for sustainable use of those resources. For instance, if the maintenance of a certain level of consumption requires that the commodity being consumed be imported, the system (landscape) must be enlarged to include the landscape units from which the commodity is being exported. Only in this way do we internalize ecological as well as economic costs.

II. The Relationship Between the Ecology Driver and the Growth and Distribution Drivers.

GROWTH

In an ecological sense, the term sustainable growth is an oxymoron. There are no ecological examples of sustainable growth. In ecological systems, physical growth (quantity) follows some variation of one of two trends: the "S" or the "J" shaped curves. Growth occurs in ecosystems only where resources are present to support it. As the carrying capacity is approached growth will often decline to zero where the quantity of biomass is in balance with the resources required to support it. This is the "S" shaped curve. In other cases, growth exceeds carrying capacity, resources are depleted, and the population crashes -- the "J" shaped curve. Modern human societies try to maintain growth by expanding the resource base available and dedicated to human needs. This was a functional system for many thousands of years while human numbers were small and there was always somewhere to which human communities could migrate once they destroyed their local environment through over exploitation. Today, such migration is not practical, because of political or economic constraints, and in many cases it is outright impossible in a pure geographical or ecological sense. There is no longer any virgin territory to tame.

This does not mean that we must abandon our desire to improve the quality of human existence. Nor does it mean that we can't have real growth in certain areas. It simply means that it is no longer meaningful or fruitful to think in terms of sustaining growth in a physical sense over an entire landscape. We need to redefine what we mean by growth and develop measures that give us an accurate picture of the state of human existence. This will require measures of ecological degradation, loss of ecological services, impacts on human health and wildlife, loss of top soil and soil productivity, etc. all of which must be subtracted from traditional measures of growth. The bottom line seems to be matching demand with supply rather than the other way around. This is the way things work in nature. We need to look to conservation and to efficiencies in production and consumption to reduce our demand for resources and our production of waste. We need to explore new modes of income production that are less damaging to the environment.

The economy of ecological systems and of landscapes is a zero-sum game that is driven by supply. Our challenge is to find ways of maintaining our legitimate non zero-sum social goals that provide us with choices and freedom within the zero-sum realities of the ecological system upon which our economic and social systems are based.

DISTRIBUTION

As ecosystems decline, much of the impact falls on the poor. It is the poor who are pushed to the marginal lands, up the steep slopes, and into the marshes and mangroves. Declining ecosystems also have a direct impact on the productivity of labor among the poor. More work is needed to extract a crop from poor or degraded land. As wood supplies retreat farther and farther from the villages, women and children must spend more time gathering the daily wood needs of the household, time away from productive activities such as working the fields and caring for children. Of the 1.2 billion abject poor in the world today, more than 600 million are trying to eke out a living on land that is declining in productivity and will continue to do so, baring extraordinary efforts at reclamation. These poor people occupy land that provides few options (crop choice, conservation, etc.), is unpredictable (productive only under ideal conditions), and is difficult to control (susceptible to erosion). There is a self-feeding spiral of poverty and land degradation in much of the developing world. How can we break this cycle? Can redistribution from more productive areas free the abject poor from their reliance for survival on marginal lands? Can redistribution keep people out of the marshes and mangroves and off of the steep slopes, relieving these systems of pressures that are destroying them and enabling them to recover and continue to provide humans with the services noted earlier?

Much of the cause of land degradation is attributable to the rich and powerful, to absentee land owners, to industries, and to users of extracted resources some of whom live thousands of miles from the site of extraction. Should these people be expected to pay for the damage that their consumption is causing? What incentives do they have to protect the land that they own? What incentives do the poor tenant farmers who work the rich man's land have to protect the land?

Is it possible that the distribution of wealth in nations where the poor occupy seriously degraded land will never become equitable? Is it possible that in such situations the poor just get poorer as they are forced to degrade their support system, the land?

TABLE 1.1 Comparison of "Conventional" Economics and Ecology with *Ecological Economics*

	"Conventional" Economics	"Conventional" Ecology	! Ecological Economics
Basic World View	**Mechanistic, Static, Atomistic** Individual tastes and preferences taken as given and the dominant force. The resource base viewed as essentially limitless due to technical progress and infinite substitutability	**Evolutionary, Atomistic** Evolution acting at the genetic level viewed as the dominant force. The resource base is limited. Humans are just another species but are rarely studied.	**Dynamic, Systems, Evolutionary** Human preferences, understanding, technology and organization co-evolve to reflect broad ecological opportunities and constraints. Humans are responsible for understanding their role in the larger system and managing it sustainably
Time Frame	**Short** 50 yrs max, 1-4 yrs. usual	**Multiscale** Days to eons, but time scales often define non-communicating sub-disciplines	**Multi-Scale** Days to eons, multiscale synthesis
Space Frame	**Local to International** Framework invarient at increasing spatial scale, basic units change from individuals to firms to countries	**Local to Regional** Most research has focused on smaller research sites in one ecosystems, but larger scales have become more important	**Local to Global** Hierarchy of scales
Species Frame	**Humans Only** Plants and animals only rarely included for contributary value	**Non-Humans Only** Attempts to find "pristine" ecosystems untouched by humans	**Whole Ecosystem Including Humans** Acknowledges interconnections between humans and rest of nature
***Primary* Macro Goal**	**Growth of National Economy**	**Survival of Species**	**Ecological Economic System Sustainability**
***Primary* Micro Goal**	**Max Profits** (firms) **Max Utility** (indivs) All agents following micro goals leads to macro goal being fulfilled. External costs and benefits given lip service but usually ignored	**Max Reproductive Success** All agents following micro goals leads to macro goal being fulfilled.	**Must Be Adjusted to Reflect System Goals** Social organization and cultural institutions at higher levels of the space/time hierarchy ameliorate conflicts produced by myopic pursuit of micro goals at lower levels
Assumptions About Technical Progress	**Very Optimistic**	**Pessimistic or No Opinion**	**Prudently Skeptical**
Academic Stance	**Disciplinary** Monistic, focus on mathematical tools	**Disciplinary** More pluralistic than economics, but still focused on tools and techniques. Few rewards for integrative work.	**Transdisciplinary** Pluralistic, focus on problems