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A SYSTEMS FRAMEWORK FOR ENVIRONMENTAL PLANNING

BY

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The undersigned certify that they have read, and recommend to the Faculty of Environmental Design for acceptance, a Master's Degree Project entitled "A Systems Framework for Environmental Planning"

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BY
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Completed in partial fulfillment of the requirementsfor
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This project is concerned with the need for a conceptual framework based on systems thinking that can be applied in environmental planning. The role of ecosystem analysis,the application of ecological theoryand systems theory, in the development of a systems framework for environmental planning are discussed.

In Section One, the importance of conceptual frameworks in the historic development of atomistic, holistic, and systems approaches in scientific thinking are discussed;and the impact these views have had on the analysis of complex natural systems is examined.

In Section Two, the relationship between conceptual frameworks and theory is presented as a basisfor introducing important features of systems theory and ecosytem theory that contribute to an understanding of system structure, function, behavior, and problems of ecosystem analysis.

Section Three describes a systems view of the planning process in order to integrate both systems theory and ecosystems theory into an environmental planning framework that involves relationships between human activity systems and ecological systems. The implications of applying a systems framework and the need for developing associated paradigms for an interdisciplinary approach to environmentalproblem solving are discussed.

In summary,the conclusions of this project include:

i) The need to develop and apply a systems approach and its associated paradigms in order to understand and work within ecological systems.

ii) The need for systems analysis in dealing with systems properties that may not be easily measureable or which by nature cannot be quantified.

iii) The use of Newtonian laws and mechanics in systems modelling may not be appropriate for describing system motion in complex indefinitely large systems.

iv) The need for ecological analysis at the macrosystem level of organizational complexity(the level of the functioning whole system)rather than the ever more detailed atomistic analysis of system componenets.

v) The need for and the application of a standardized vocabulary of systems terminology.

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PREFACE

"The man who seeks to understand nature needs to get beneath its surface; he must look and admit that looking is not enough. He must weigh it without a hoist, measure it with ancient yardsticks, while always seeking something better for the job. . .The artist who sketches a scene knows more about the landscape than when he first cast eyes upon it; the sculptor can tell us of qualities in wood and stone no eye alone can see. . .Merely looking at nature is seldom enough for those who hope to enjoy it, and this act is hardly more than a start for those who intend to change it. . .If one is to progress from sight to insight, the essential first step is painstaking and repeated observation; perspiration as well as inspiration. For it is to the landscape resources that we must turn and turn again; here is the beginning of all environmental design."

- Grady Clay

(1963)

INTRODUCTION

INTRODUCTION

The decade of the 1960's, particularly in North America was a significant period of social awareness and change. Existing idealogical structures and values were questioned at all levels of social organization. Our views of ourselves as individuals, and our relationships with others and our environment were re-examined. Within this milieu, a number of major social/political 'movements' developed during the 1960's. One of the most popularized and publicized of these, was the so-called 'environmental movement'. By the end of the decade, public awareness of environmental issues had assumed almost obsessive proportions. Pollution, population, and resources, were the central issues around which a resurgence of Malthusian theory generated the threat of ecological disaster. The problems posed in this first wave of environmental awareness focused attention on the need to understand human interactions within the context of the Biosphere. As a result, the science of ecology, traditionally considered as the study of interrelationships between organisms and their environment (Collier, Cox, Johnson, and Miller, 1973), became the focal point of the environmental movement. Ecology assumed prominence and relevance as a "science for survival" (Collier et al, 1973).

However, the science of ecology was as much a 'victim' of the environmental movement as it was a 'prophet'. Ecology was a relatively young scientific discipline at the time; a little known branch of biology in its own stages of transition and development. Although popularly viewed as a panacea for environmental problems, ecology was not waiting with immediate solutions to the 'newly' identified problems of the 60's, that were in fact manifestations of a long term cycle of interacting social, political, technological, and biological processes. Prior to the environment conscious 60's, the pressures on the environment as a result of these processes had been successfully ignored, not only by government, industry, and agriculture, but by science as well. Smith (1976) states, "Science, comfortable with its atoms and molecules and physical measurements, ignored the environment. Answers to the problems of life were to be found in biochemistry, and the rapidly developing environmental problems could be solved by technology."

This long term cycle of interacting social, political, technological and biological process is involved in the concept of "demophoric growth" (Wetzel, 1975), defined as the combined effects of increasing population in a biological sense, and production and consumption in a technological sense. The result of such growth to date, with its associated social, economic, and political factors, has been a continuing cycle of biospheric degradation. By the middle of the 1970's, the environmental movement had entered its "second generation" stage (Gorden and Gorden, 1972). The environmental problems identified in the 60's were recognized as more than biological problems requiring ecological solutions. The problems of the 60's were still present and more complex with the addition of the 'energy crisis' of the early 70's. The second generation environmental movement of the 70's recognized the interdisciplinary nature of environmental problems and solutions. Environmental problem solving in the 70's has been characterized by a developing ecological, economic, and social approach to environmental issues within a framework based on the ecosystem concept. For example, in 1965, ecologist F. Fraser Darling in his introductory remarks to the 'Future Environments of North America' Conference, criticized ". . .planners and landscape architects who have no biological knowledge although they are dealing with the living landscape. . .". In the decade since, this criticism has not been ignored, particularly within the field of landscape architecture and the "Design With Nature" approach of Ian McHarg (1969). Within the context of a second generation interdisciplinary problem solving approach of the late 1970's, Darling's 1965 criticism might well be expanded to include ecologists, with no knowledge of planning or design, attempting to change human interactions with the living landscape.

The attention and pressure focused on ecology as the potential source of environmental solutions has resulted in a dramatic increase in knowledge of dynamic ecological systems over the last fifteen years. The Science of Ecology has become primarily concerned with the study of the structure, function, and behavior of ecological systems (Johnson, 1977). Regardless of the importance of understanding dynamic ecological systems in order to solve environmental problems, the importance of interrelated social, political, and technological factors in providing solutions cannot be ignored. Understanding and solving complex environmental problems requires the integrated knowledge and theory of many disciplines. To this end, ecology is part of a larger interdisciplinary field that was developed within the 70's. Environmental Science is the interdisciplinary field concerned with understanding the interactions between human activities and the biophysical environment in order to plan and manage human/nature interactions for the mutual benefit of both (Johnson, 1977). Such an interdisciplinary approach to environmental problems is necessary in order to:

- Develop a theoretical framework or paradigm for viewing environmental problems.
- Synthesize relevant information from many different disciplines involved in environmental problems.

- Identify and utilize integrated principles or theorems for application in the practice of environmental planning, management, and design.

The importance of the science of ecology in the interdisciplinary context of environmental science (apart from its contribution of empirical knowledge) is the theoretical framework it provides for dealing with complex networks of environmental interrelationships. The ecosystem concept provides a framework that encompasses complex networks of biophysical interrelationships requiring knowledge from such fields as botany, zoology, geology, hydrology, meteorology, chemistry, physics, and mathematics.

The ecosystem concept, central to ecology, is the basis of the 'ecosystem approach' to interdisciplinary problem solving in environmental science.

If the science of ecology is to be an effective agent of environmental change it must be able to apply its knowledge of ecosystem structure, function, and behavior, within the interdisciplinary ecosystem approach of environmental science. However, the transition from theory to practice is not a simple step. It cannot be assumed that:

- A current, acceptable paradigm is in use that clearly provides the conceptual and contextual framework (and associated assumptions) upon which ecosystem science is based.

- A unified body of ecosystem theory exists that can be put into practice and applied to any or all situations without the risk of being dogmatic or impractical.

In fact,

Although knowledge of dynamic ecological systems has increased dramatically over the last 15 years, ecologists are still unable to:

- Identify a common set of unifying principles or theorems that underlie ecosystem science (Johnson, 1977).
- Understand ecosystem structure, function, and behavior sufficiently to ". . .predict with useful precision the consequences of ecological perturbations" (Johnson, 1977).

Conceptual development is a necessary process in both the development of theory and its application in practice. The conceptual frameworks and paradigms associated with this process have important theoretical and practical implications and characterize a discipline's approach to its field of study.

An integrated approach to the practice of environmental science requires conceptual development as well as the application of theory. To this end, ecologists and environmental scientists must be involved in the following four activities:

i) The development and evaluation of conceptual frameworks and paradigms that have theoretical and practical implications.

ii) The identification and utilization of unifying principles or theorems for the structure, function, and behavior of ecological systems.

iii) The development of techniques for applying conceptual frameworks, paradigms, and theory, to problem solving in environmental planning, management, and design.

iv) The evaluation and reconsideration of the usefulness of existing frameworks, theory, and empirical approaches to interdisciplinary problem solving.

The purpose of this Master's Degree Project is to identify the contribution of a 'systems view' to these four activities.

PROBLEM DEFINITION

Neither the definition of a specific problem, nor its solution, can be viewed in isolation even though the definition must eventually bound the problem. The specific problem addressed by this project exists within the context of a larger, more general problem area within which it is related to associated problem areas.

The general problem area this project is concerned with is the application of the science of ecology and general systems theory to the interdisciplinary practice of environmental planning.

Specifically, the problem addressed by this project is the identification of a conceptual framework and paradigm based on systems thinking that can be applied in environmental planning.

The primary problem area associated with this specific problem is the process of ecosystem analysis in ecology, in terms of both the frameworks and techniques of analysis.

Important aspects of both the general problem area and the primary associated problem area, relevant to resolving the specific problem, will be identified and discussed.

PROJECT GOALS AND OBJECTIVES

Objectives represent the ends to be obtained or achieved through the successful completion of directed actions. Goals refer to the steps or sequence of actions required to achieve one or more objectives.

The following goals and objectives have been identified for this project:

A. Goals:

i) To present the conceptual and theoretical background that supports a systems approach.

ii) To identify the important features of systems theory involved in the ecosystem concept and ecosystem structure, function, and behavior.

iii) To sort through the myriad of systems descriptors and taxonomy and provide a lexicon of relevant descriptors.

B. Objectives:

i) Identify and describe a conceptual framework and paradigm based on systems theory applicable to environmental planning.

ii) Present and discuss important aspects of system theory that contribute to a better understanding of the nature and application of systems ecology.

iii) Identify and discuss the problems of ecosystem analysis in terms of the analytical frameworks and techniques involved.

iv) Discuss the implications of a systems framework for an inter-disciplinary approach to environmental problem solving.

PROJECT ORGANIZATION

The project has been organized into three sections: conceptual development, theory, and practice.

Section One, conceptual development, is concerned with identifying the importance of conceptual frameworks in the historical development of scientific thinking, and the impact these views have had on the analysis and understanding of complex natural systems.

Section Two, theory, discusses the relationship between conceptual development and theory as a background for presenting important features of general systems theory and ecosystem theory that contribute to an understanding of system structure, function, and behavior, and the problems of ecosystem analysis.

Section Three, practice, incorporates conceptual development and theory into an environmental planning framework based on the systems approach to the relationships between human activity systems and ecological systems. The implications of applying this framework to environmental problem solving are discussed at the end of the project.

SECTION ONE:

CONCEPTUAL DEVELOPMENT

"If science is not to degenerate into a medley of ad hoc hypothesis, it must become philosophical and must enter upon a thorough criticism of its own foundations"

- Alfred North Whitehead
(1925)

CHAPTER ONE: DEVELOPMENT OF THE SYSTEMS APPROACH

INTRODUCTION

The concept of systems has existed in some form since earliest times (Shultz, 1969). It is a concept of integrated 'wholes', acting as such, inseparable, interacting, and dynamic. The systems concept involves an awareness of the unity and interrelation of things and events as interdependent inseparable parts of a basic 'oneness' or 'whole' (Capra, 1975).

This systems view is described by Laszlo (1972) as "thinking in terms of facts and events in the context of wholes, forming integrated sets with their own properties and relationships and looking at the world in terms of such integrated relations. . .".

The systems concept and the systems view are based on relationships, either abstract or empirical, between things or events through both space and time. A system, as a functioning whole, is connected by these relationships. The critical factor is the organizational pattern or structure created by the parts and the relationships between parts. It is this factor which distinguishes systems and the systems concept from a collection or aggregate of facts, objects, or events. Within an aggregation, the parts have no organizational relationships and can be randomly added. Because the parts of a system are organized, new parts must be integrated and arranged within the system rather than simply added.

The systems view is one of integrated wholes not a mechanistic aggregate of parts.

A CONCEPTUAL FRAMEWORK FOR THE SYSTEMS VIEW

A conceptual framework is an abstract organizational pattern used to view events or phenomena. In this sense, it functions as both a tool and 'standard' for analysis, comparison, and evaluation. Rational knowledge is based on empirical experience of the things and events within our day to day environment (Capra, 1975). It involves intellectual distinctions, divisions, comparisons, measurements and categorization. A critical part of rational knowledge is abstraction, or abstract thinking, which enables the comparison of events and things to be simplified by 'abstracting' significant patterns or commonalities.

Abstract or conceptual thinking is used to ". . .construct an intellectual map of reality in which things are reduced to their general outlines. . ." (Capra, 1975).

Conceptual frameworks present an approximation of reality, that the rational knowledge of science can then measure, analyze, and classify.

The function of conceptual development in the empirical approach of science is to develop abstract or conceptual frameworks that approximate reality and provide a pattern of organization from which to view phenomena. From such a 'view' comparisons and distinctions between objects and events can be established and tested. The way in which phenomena are conceived to occur relates directly to the way in which they are analyzed. The approaches used to understand complex systems are dependent upon the way such systems are viewed or conceived of by a particular conceptual framework.

However, conceptual frameworks are not absolutes, rather they are relative approximations of reality. There is an inherent danger in using such conceptual 'knowledge' because such approximations of reality are much easier to understand than reality itself. As a result, there is a tendency to confuse reality with the symbols and concepts representative of our perceived reality.

A conceptual 'view' of the natural world is universal and dates back to antiquity. Historically, the development of scientific thinking reflects changing conceptual views of the natural world.

Two major approaches for understanding natural phenomena have dominated classical and modern scientific thinking. These are the holistic and atomistic approaches. The holistic approach conceives of 'wholes'. It is concerned with gaining an understanding of a bigger or total picture rather than the parts that compose it. The atomistic approach conceives of wholes as composed of 'parts' and is concerned with breaking down complex phenomena into smaller and smaller parts which can be more easily analyzed by the scientific method. Both approaches, if treated or viewed independently from each other are restrictive.

The atomistic approach encourages the acquisition of empirical data using available methods, often with little or no rationale for their compilation outside the immediate bounds of the problem under attack, and/or very little understanding of their interrelationships.

The holistic approach sometimes encourages generalization and abstraction without a solid empirical foundation.

It should be recognized that both approaches involve rational knowledge and as such are only approximations of reality. As stated by Heisenberg (1963), "As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality."

A synthesis of the two approaches (holistic and atomistic) is necessary if a conceptual framework incorporating both theoretical constructs and their supporting empirical data is to be used effectively. Both the 'whole' and the relationships between its 'parts' must be considered. A detailed knowledge of parts will not necessarily provide a knowledge of the whole; neither will a knowledge or conceptual grasp of the whole necessarily provide a detailed knowledge of the parts.

The rapid expansion of knowledge in ecology over the last 15 years has been affected by this conflict between holistic and atomistic approaches. This expansion of knowledge has been the result of collecting empirical data from autecological (individual species), population, and community levels of ecological organization. In order to understand the structural components, functional processes, and behavior of 'whole' ecological systems, ecologists have attempted to synthesize the data gathered from 'parts' of 'whole' ecosystems. To date this approach to synthesis has not been completely successful and as Johnson (1977) points out ". . .has frequently become bogged down in mechanistic data processing as a result of the burden of unsynthesized empirical data."

The following review of evolving conceptual frameworks in the history of scientific thinking is important to this project's concern with identifying a framework for developing and applying ecosystem theory to environmental planning because it traces the conceptual development of the systems approach; an integrated alternative to either the holistic or atomistic approach.

The development of scientific thinking from the earliest protosciences through classical and modern stages illustrates a changing 'view' of the world. These changing conceptual frameworks and the techniques and theories associated with them illustrate the approximations of reality of the time and the advances toward a better approximation with each succeeding stage.

A review of the trends in the history of scientific thinking can be a valuable tool in understanding both the roots of contemporary science and the evolving conceptual frameworks that influence our view of the natural world. Such a review also illustrates the interrelationship between the theories and techniques used to analyze natural phenomena and the conceptual frameworks from which they developed.

The beginning of Western science is associated with the first period of Greek philosophy in 6th Century B.C. (Laszlo, 1973; Capra, 1975).

The Milesian school of thought (Capra, 1975), held essentially a holistic view of the cosmos. The universe was viewed as an organism supported by the "pneuma" or cosmic breath.

Heraclitus of Ephesus, conceived of the world in terms of perpetual change and eternal 'becoming'. All change was the result of a unified, cyclic, and dynamic interplay. Static 'being' was considered as sensory deception. The universal principle was one of continuous flow and change.

The split from this holistic, dynamic view originated from the Eleatic school of thought (Capra, 1975), which conceived of a 'divine' universal principle for the unity of the universe, later interpreted as an intelligent God. The philosopher Parmenides of the Eleatic school opposed the dynamic principle of Heraclitus. The basic universal principle of Parmenides was 'being', rather than 'becoming'. Change was considered as illusion, and the state of 'being' was conceived as the unique and invariable universal principle. This view still remained essentially holistic, but was a static holistic approach, rather than a dynamic one.

The holistic views of Heraclitus and Parmenides were replaced by the atomistic view of Democratis and the Greek Atomist school of thinking (Capra, 1975). The Atomistic school developed from an attempt to reconcile the contradiction between the concepts of static being and dynamic becoming. The atomists viewed the world as composed of certain unchanging substances which, when combined or separated, resulted in change. The property of static being belonged to these basic unchanging substances while dynamic becoming resulted from their mixture or separation. All matter was conceived to be composed of these basic inanimate substances. The movement, mixing, and separating of matter was conceived as the result of spiritual forces fundamentally different than matter. The result of this view was the division between spirit and matter.

Greek atomism had a profound effect on the conceptual development of Western science, philosophy, and religion, for well over 2,000 years.

The two basic atomistic concepts; the dualism of spirit and matter and; that all matter is composed of basic building blocks, and can therefore be understood by breaking it down to its smallest units; formed the basis (centuries later) for the 'mechanistic view' of the world which culminated in Newton's theories of classical physics. This development is illustrated by Figure 1.

The beginnings of modern science, in terms of scientific method, developed in the late 15th century. Empiricism replaced speculation and the divinely ordered basis of the Greek protosciences. Galileo's combination of the empirical approach of testing by experiment and experience and mathematics is associated with the beginning of modern scientific process. However, the science of Galileo was still based on the Greek atomistic concept and used a static framework for viewing the universe. Galileo's use of mathematics was consistent with the Pythagorean doctrine that "number" lies at the base of the natural world (Whitehead, 1925). This approach established an alternative to the spiritual or divine explanation for the behavior of matter that enabled a re-evaluation of Greek spirit/matter dualism. In the 17th century, Rene Descartes developed the "cartesian division" (Capra, 1975) which represented a reformulation of the dualism concept. In the Greek concept the realms of spirit and matter, while fundamentally different, were not mutually exclusive. Physical change was conceived as the result of spiritual or divine forces acting upon matter.

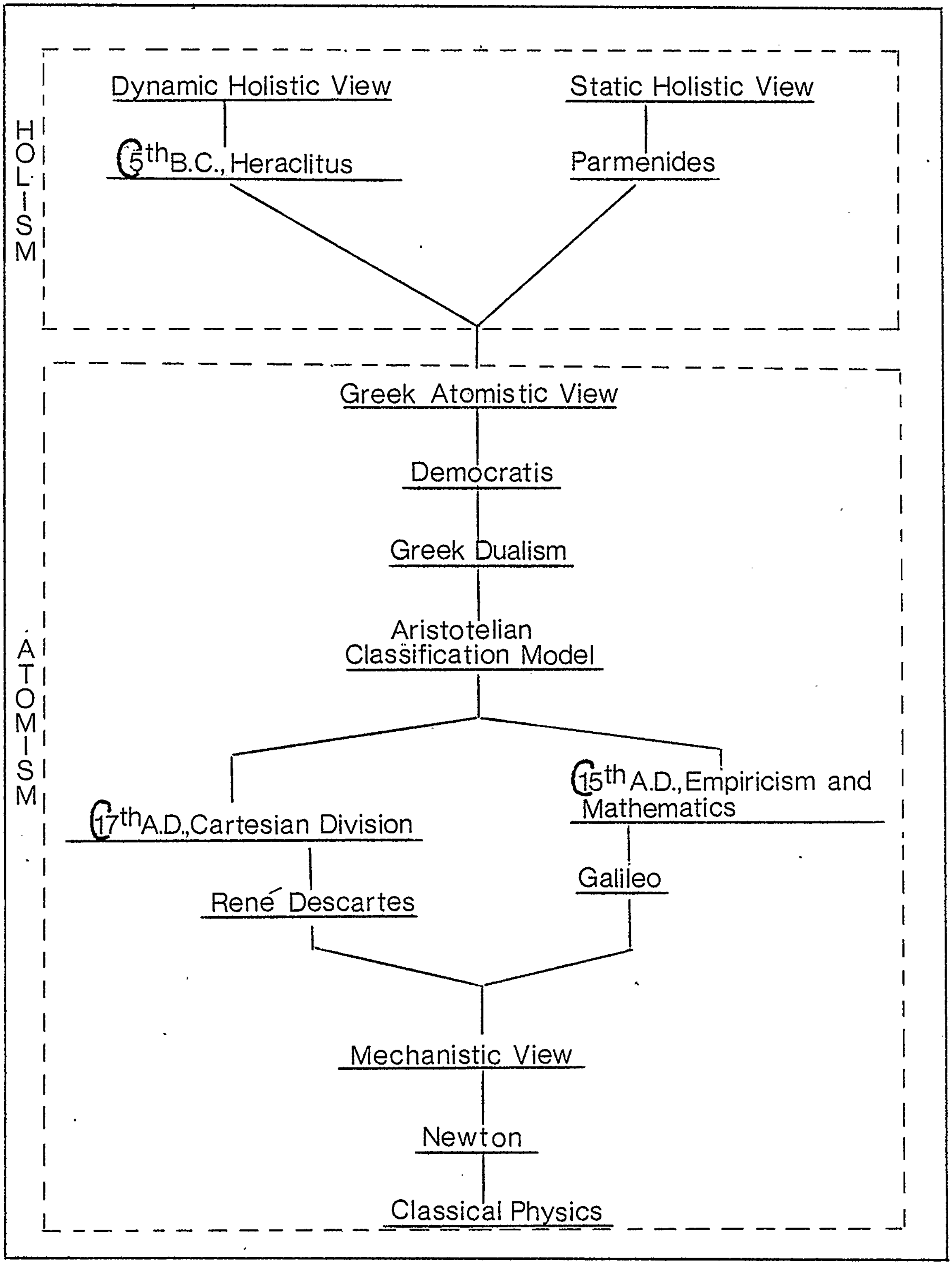


FIGURE 1
The Rise of the Atomistic Approach

Descartes viewed the world in terms of two separate and mutually exclusive realms; mind in the sense of spirituality and matter (both organic and inorganic). The human species because of the attribution of spirituality or 'mind' was distinct and separate from animals, plants, and inorganic (non-biological) matter. Within this framework, empiricism was interpreted as truly objective since scientists were intrinsically separate and independent from the physical world. Mathematics assumed great scientific importance since, as the base of the natural world, it was applicable to the realm of matter and could therefore be used objectively by scientists to explain the behavior of the physical world.

Empiricism, mathematics, and the Cartesian division between 'mind' and matter, all contributed to the rise of the deterministic and mechanistic framework of modern science which was characterized by a static atomistic approach. The conceptual framework of the mechanistic view was that of a "cosmic machine" (Laszlo, 1972; Capra, 1975) composed of parts that operated according to fundamental mathematical laws. Capra (1975) describes the mechanistic view of the world as follows; "All that happened had a definite cause and effect, and the future of any part of the system could, in principle, be predicted with absolute certainty if its state at any time was known in all details." This description illustrates a fundamental problem of the mechanistic view. In principle, if all details are known, the behavior of phenomena (other than human behavior) can be predicted. However, in reality, the complexity of phenomena can be such that we cannot or do not know all the details, and the phenomenon becomes unpredictable. Further, although in principle the future of any part of the system can be predicted; the future of the system as a functioning whole cannot be predicted since a system is more than the sum of its parts. For example, a chess game involves a number of pieces or parts but the game of chess involves concepts and relationships beyond that of its parts. Knowing about the pieces involved in the game of chess does not constitute a knowledge of the game itself.

The mechanistic view was the basis of Newton's mechanical model of the universe (Capra, 1975). The view of Newtonian mechanics, was similar to that of Democritus and the Greek atomists in that all phenomena were reduced to the motions and interactions of atoms, the concrete physical 'building blocks' of matter. However, Newton's model of the universe provided the force of gravity and equations of motion to account for the physical movement and interaction of matter.

In Newton's world view, all physical events occurred in the absolute, static, three-dimensional space of Euclidean geometry. All observed changes in the physical world were the result of particles of matter (composed of atoms) moving in absolute space and absolute time according to fixed laws of motion. In the Newtonian view, time was a separate dimension independent of the physical world.

Newton's mechanistic model provided the conceptual framework of classical science for almost three centuries (Capra, 1975). The success of the mechanistic view, its simple cause and effect relationships, and the reduction of all natural phenomena to such mechanistic behavior, encouraged a deterministic and reductionist approach to understanding natural phenomena. Whereas early Greek thinking was holistic to an extreme and lacked factual inquiry; modern scientific thinking, while empirical, was extremely atomistic and placed rigorous detailed knowledge of mechanistic "parts" above all other considerations (Laszlo, 1972).

The mechanistic theory of modern science began to break down in physics, the discipline in which it was most successfully applied. The discovery and investigation of electric and magnetic phenomena by Faraday and Maxwell (Capra, 1975) could not be described or explained by Newtonian mechanics since these phenomena involved a force other than gravity. Parallel developments emerged in other disciplines; in biology, Newtonian laws were unable to explain complex interactions within living organisms.

The development of Einstein's theory of relativity and quantum theory, represented a conceptual framework completely different from the mechanistic deterministic approach of Newton. This was a necessary result of the theory of relativity, that involved a different concept of space and time than Newtonian mechanics. The concepts of space and time are basic to the description of natural phenomena. A conceptual change as different as that of Einstein's, therefore required a modification of the whole framework used to view the natural world.

Relativity theory (Capra, 1975) augmented Newtonian concepts of absolute three-dimensional space and absolute time with the concept of a four-dimensional space-time continuum. Within this framework, time is no longer considered a separate dimension and different observers will therefore order events differently in time if they move with different velocities 'relative' to the observed events.

Einstein's quantum theory (Capra, 1975), destroyed the atomistic concept of solid objects composed of independent smallest units following fixed deterministic natural laws.

Quantum theory deals with the mathematical descriptions of the subatomic level of matter. This submicroscopic level is beyond that of our everyday sensory perception. At this level the solid material 'atoms' of classical physics are described as patterns of probabilities. Such patterns are not probabilities of 'things', but rather probabilities of interconnections. Matter, at this level, is not composed of isolated building blocks; rather, it is described as a complicated, probabilistic web of inseparable energy patterns.

Within Einstein's conceptual framework the classical concepts of elementary particles, material substance and isolated smallest units had no meaning. This does not mean that Newton's model was 'wrong', or that Einstein's theories were 'right'. As stated earlier, conceptual frameworks are approximations of reality which provide a pattern of organization or context in which phenomena can be viewed and ordered for the purpose of establishing and testing relationships between objects and events. A certain group of phenomena can then be singled out of the whole range of natural phenomena and a theoretical model developed to describe it; subject to empirical testing. Theoretical models are also approximations, since they cover only a limited group of phenomena over a limited range; subject to empirical testing.

Newtonian mechanics are valid for the motion of solid bodies in the "zone of middle dimensions" (Capra, 1975), or the range of the natural world that can be perceived by the senses. Einstein's quantum theory deals with the zone of the indefinitely small, a range that cannot be perceived by the senses.

The phenomena selected for study during the atomistic period of scientific thinking were part of the macroscopic environment, within the range of sensory experience. The images and intellectual concepts expressed in language are abstractions of this sensory experience and therefore adequate to describe perceived natural phenomena at this scale.

Atoms, the atomic and subatomic world, are not part of the realm of sensory experience; nor in the same respect is the indefinitely large.

However, atoms in the Democritean and Newtonian sense (Capra, 1975) were described by the images, concepts, and properties, abstracted from sensory experience in the macroscopic world. Recognition of the limitations of both Newtonian mechanics and the atomistic view resulted from both Einstein's theories and the development of 20th Century technology. Einstein provided the conceptual framework and theory for a realm of the natural world outside of sensory experience. Technology (much later) provided the tools for testing and exploring this realm.

However, the difficulty of understanding a conceptual framework such as Einstein's that had no correlate in the macroenvironment and was not based in sensory experience, contributed to the persistence of classical thinking and concepts. For example, the discovery of protons, neutrons, and electrons meant that atoms were not the basic units of matter. This was not seen as evidence to support quantum theory but rather was conceived as a refinement of the atomistic view. By the early 1930's (Capra, 1975) protons, neutrons, and electrons had replaced atoms as the smallest indestructive units of matter in the Democritean and Newtonian sense. Almost thirty years later, the empirical evidence to support quantum theory and Einstein's conceptual framework was provided by the technology developed for high energy physics.

The results of high energy scattering experiments of subatomic particles (Capra, 1975) showed all particles can be changed into other particles. They are created from energy and disappear into energy. At this level there is no physical material substance only dynamic probabilistic patterns of energy; at least when observed by high energy physics technology and described by quantum mechanics.

Einstein's theories and high energy physics had four major effects on the conceptual development of scientific thinking:

i) They showed the basic atomistic concept that all matter is composed of physical concrete building blocks to be incorrect.

ii) They presented an empirically supported dynamic, probabilistic view of the natural world in contrast to the static, mechanistic, and deterministic views associated with the atomistic approach.

iii) In high energy physics experiments, the experimental 'probe' used by the human observer is an integral part of the process. The properties of atomic and subatomic phenomena can only be understood in terms of the observer's interaction relative to the event. This is consistent with Einstein's space-time continuum and the theory of relativity. In this situation at least, the Cartesian division and its associated ideal of objective description are not valid.

iv) The conceptual framework implicit in Einstein's theories is essentially a dynamic, systems view. The view of quantum theory is that of a basic 'oneness'. The world is conceived of in terms of complex probabilistic webs of relationships, an interconnected, interrelated, interdependent whole.

The conceptual framework provided by Einstein's theories coupled with the breakdown of the mechanistic view in physics and the life sciences led to the development of a new approach in contemporary Western science.

The world view of contemporary science is that of organized complexity. Contemporary thinking is concerned with relationships and organizational complexity. The importance of this view is described by Laszlo (1972);

"Knowledge of connected complexity is preferable even to a more detailed knowledge of atomized simplicity, if it is connected complexity with which we are surrounded in nature and we ourselves are a part."

The development of the systems approach and systems theory, is a logical extension of a world view that conceives of relationships between things and events in terms of integrated wholes or systems. The historical conceptual development of this systems framework is represented by Figure 2.

As a conceptual framework, the systems view provides an abstract pattern of organization for viewing events and phenomena.

Systems thinking represents a paradigm in contemporary Western science because it provides a pattern or theoretical structure for viewing natural phenomena.

The distinguishing factor of the systems concept has previously been identified as organization. The parts, and relationships between parts, are organized to form a functioning whole. In this sense, the structure of a system is a critical factor in understanding the nature of a system.

The formal development of "General Systems Theory" by Von Bertalanffy (1950) was therefore extremely important to systems thinking. It provided the theoretical framework for identifying common organizational features of structure which could be represented symbolically.

If phenomena can be viewed in a systems framework, they can be analyzed in a systems framework.

The ability to abstract common organizational principles from seemingly different phenomena enabled comparisons and distinctions between objects, events, and relationships to be established and tested. The systems approach provides an integrated alternative to both the holistic and atomistic approaches of scientific thinking. It assimilates the holistic concern for 'wholes' with the atomistic focus on 'parts' within a framework

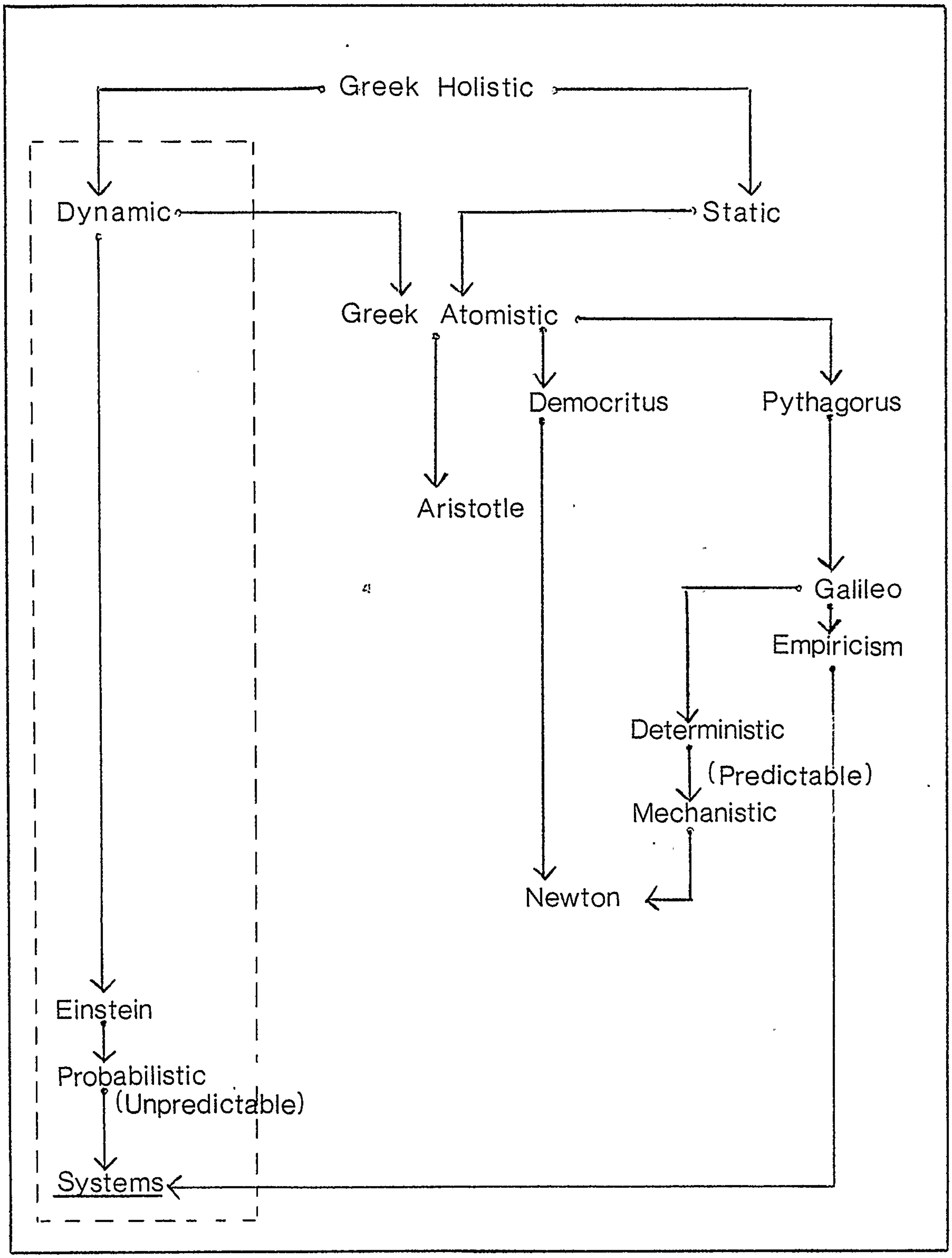


FIGURE 2
The Development of Systems Thinking

that is concerned with the organization of relationships between parts in the context of a functioning whole.

This distinction between the relationship of parts and the functioning whole must be emphasized. It is based on the previous distinction between a system and an aggregate. By definition, an aggregate has no organizational relationships between its parts and therefore represents the sum of its parts. However, a system, at the organizational level of a functioning whole is more than the sum of its parts. Water (H_2O) is an example of this principle. Water is composed of two elements, hydrogen and oxygen. However, hydrogen and oxygen are not simply added together to form water. The process of chemical bonding creates an organizational relationship between these two components.

The systems approach provides the emphasis on interrelationships lacking in the atomistic approach. The logico-mathematical field of general systems theory provides the systems approach with an empirical foundation lacking in the holistic approach.

As previously stated, conceptual frameworks present an approximation of reality. The conceptual framework inherent in the systems approach is such an approximation. The theories that develop from a particular view of the world or conceptual framework are necessarily approximations and simplifications of reality.

While systems theory is a simplification, it is not reductionist in the atomistic sense (Laszlo, 1972). The systems approach may appear to 'reduce' all phenomena to the behavior of systems, in much the same Newtonian atomism reduced all physical phenomena to the motion of atoms. However, the common denominator sought by the systems approach is organizational relationships; not a single shared element. Whereas the systems approach is concerned with organizational structure; reductionism eliminates this structure. Laszlo (1972) explained this distinction as follows;

"Classical science and natural philosophy abstracted substance and causal interactions between substantive particulars. Contemporary science tends increasingly to concentrate on organization: not what a thing is per se, nor how one thing produces an effect on another thing but rather how sets of events are structured and how they function in relation to their 'environment' - other sets of things likewise structured in space and time."

Science is based on rational knowledge (Capra, 1975); a critical part of which is abstraction.

Abstraction enables the comparison of events or things to be simplified by identifying significant patterns or commonalities.

The importance of the systems approach to contemporary science is the conceptual framework and the empirical body of theory it provides for abstraction.

SECTION TWO:

THEORY

"It is not the star that is small and the planet which is big, it is only man's view of things which is so distorted."

- L. Eiseley

(1961)

INTRODUCTION

RELATIONSHIPS BETWEEN CONCEPTUAL DEVELOPMENT AND THEORY

The function of abstraction has been described in Section One as the identification of significant patterns or common features from some group of phenomena. This function enables the distinctions, divisions, and comparisons, involved in rational knowledge to be simplified. This simplification is described by Einstein (Pirsig; 1974):

> "...Man tries to make for himself in the fashion that suits him best a simplified and intelligible picture of the world. He then tries to some extent to substitute this cosmos of his for the world of experience, and thus to overcome it...he makes this cosmos and its construction the pivot of his emotional life in order to find in this way the peace and serenity which he cannot find in the narrow whirlpool of personal experience... The supreme task...is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction. There is no logical paths to these laws, only intuition, resting on sympathetic understanding of experience, can reach them..."

The process of abstraction is used in the system appraoch at both the conceptual and theoretical level:

- At the conceptual level, abstraction is used to "...construct an intellectual map of reality in which things are reduced to their general outline" (Capra, 1975).

- At a theoretical level (using the above analogy) abstraction is used to construct a more detailed intellectual map of a specific area, or some group of phenomena.

Theoretical developments occur within the general outline provided by a conceptual framework. As a result, a theory almost by definition, is consistent with the conceptual framework within which it is constructed. For example, the atomistic approach of modern science presented a mechanistic view of the natural world that culminated in the development of Newtonian theory; a mechanistic, atomistic, theoretical construct.

The conceptual framework of atomism abstracted a common feature or substance of the natural world; atoms. Newtonian theory abstracted a common substance, atoms, and a common force, gravity, for a specific group of phenomena; solid bodies in space.

The conceptual framework provided by the systems approach views the natural world in terms of integrated 'wholes', and abstracts their organizational relationships. Systems theory, represents the body of rational knowledge resulting from the abstraction of common or non-varying aspects of organizational relationships from integrated wholes or systems in general.

The purpose of theory within the framework of scientific process is to describe and/or explain some group of phenomena. Margenau (1950) states; "...There is no intrinsic difference between scientific description and explanation". Rather than being polarized concepts, describing 'how' something works and explaining 'why' something works is a continuum of refinement or logical reduction. Understanding how something works is a logical prior stage to understanding why it works..."

Depending upon the nature and complexity of a phenomenon several stages of refinement or reduction may be required to provide an acceptable 'why'. For example, consider the phenomenon of gravitation (Margenau, 1950):

i) The first level of logical reduction was represented by the descriptive thesis of Aristotle. According to Aristotelian theory, terrestrial objects fall because they seek their natural place.

ii) At the second level of reduction, Galileo formalized and improved upon Aristotle. Galileo postulated and demonstrated that solid bodies fall as they do because of constant acceleration.

iii) At the third level of reduction, Newton generalized and improved upon Galileo's theory with the development of the law of gravity.

iv) The fourth level of reduction, and the most recent accepted level of refinement is represented by Einstein's theory. Einstein generalized and improved upon Newton's theory by interpreting the force of gravity within a four-dimensional space-time continuum.

v) Currently, experiments to measure gravitational waves are being prepared which may result in a further, fifth level of refinement.

The levels of theoretical development and refinement represented in this example illustrate the logical progression from theoretical constructs based on observation of a phenomenon to theories based on abstract concepts of the structural basis for phenomena; in this case, beyond the range of sensory perception. This sequence of refinement is still an approximation of reality.

Iberall (1972) identifies three levels of formal explanation within this continuum of logical reduction:

i) Heuristic - "The level at which the elements and relations that are discovered in a field of phenomena are named and ordered."

ii) Phenomenological - "The level at which the functional transformations that may occur in space and time are described".

iii) Analytic - "The level at which the elements, relations, and functions, are condensed into an abstract form which may then undergo manipulations without reference back to the physical field of phenomena."

Determining an acceptable level of theoretical explanation is dependent upon the nature of the conceptual framework within which the theory is developed. For example, theoretical constructs that constitute a satisfactory level of reduction or refinement within an atomistic/mechanistic framework provide a 'mechanical' or phenomenological level of explanation.

The conceptual framework provided by the systems approach abstracts organizational relationships of integrated 'wholes', regardless of their nature. As such, the systems view encompasses abstract concepts, social and mental processes, living organisms, and non-living things, at any level of organization (indefinitely large, indefinitely small, or in the zone of middle dimensions).

Within this framework, systems theory abstracts non-varying aspects of organizational relationships and provides a given level of explanation for a given level or organization. Systems theory provides; heuristic, phenomenological, and analytical levels of explanation, since all three levels involve organizational relationships at some level of complexity.

The basis for this general application of systems theory to all levels of explanation is inherent in the nature of the systems concept since the act of defining a system represents in itself selecting some level of resolution or logical reduction within a continuum of organizational relationships from indefinitely small to indefinitely large.

Although Newtonian theory encouraged a 'mechanistic' view of the world and encorporated the philosophy of Greek atomism, Newton's work and his use of the scientific method was not 'atomistic' in the reductionist sense. The scientific approach or method used by Newton was the same as the science used by Einstein.

Systems theory does not eliminate cause and effect. However, it deals with it in terms of relationships within the context of functioning wholes rather as an isolated function between two variables. The difference between a systems approach and a non-systems approach is pragmatic. A systems approach is not concerned with developing general causal theories to explain the function of physical phenomena. A systems approach is concerned with the input-output relationships of a selected system which are of importance for some pragmatic purpose. In contrast, the intent of both Newton's and Einstein's theories was to explain the function of universal physical phenomena. Neither Newton or Einstein used a systems approach. The difference between their theories is the level of explanation they provide. The theoretical constructs postulated by Einstein provided a more comprehensive level of explanation for universal phenomena than Newtonian theory.

CHAPTER TWO: ELEMENTS OF SYSTEM THEORY

The theoretical constructs of general systems have developed within the conceptual framework of the systems approach. The approximation of reality presented at the conceptual level of systems thinking is that of a continuum of organizational relationships. Reality is conceived of as a unified, continuous, functioning whole. The basic pattern of organization, abstracted from this continuum, is a hierarchy of ordered relationships illustrated by Figure 3.

Systems theory is an isomorphic type of theory, in that it sets up a conceptual structure that approximates the 'real' structure of the phenomena under study. In the metaphorical sense (Iberall, 1972), "It is the scaffolding which outlines the form that is close to the real structure though it is not quite the structure itself."

Isomorphic theories or models are in a one to one correspondence with the phenomena they attempt to explain and are therefore analogous to the real phenomena. For example, 'systems' per se, are not physically concrete observable objects in the same sense as a car, or a building, or a tree. However, cars, buildings, or trees can be conceived of as systems.

Systems theory is a body of conceptual isomorphic constructs that apply to real phenomena which are conceived as systems by analogy to the definition of a general system. Phenomena become systems by analogy or one to one correspondence to the concept of a general system. As a system, the phenomenon is subject to the same theoretical constructs or principles that apply to general systems.

THE GENERAL SYSTEMS CONCEPT

Von Bertalanffy (1950) defines a general system simply as "a complex

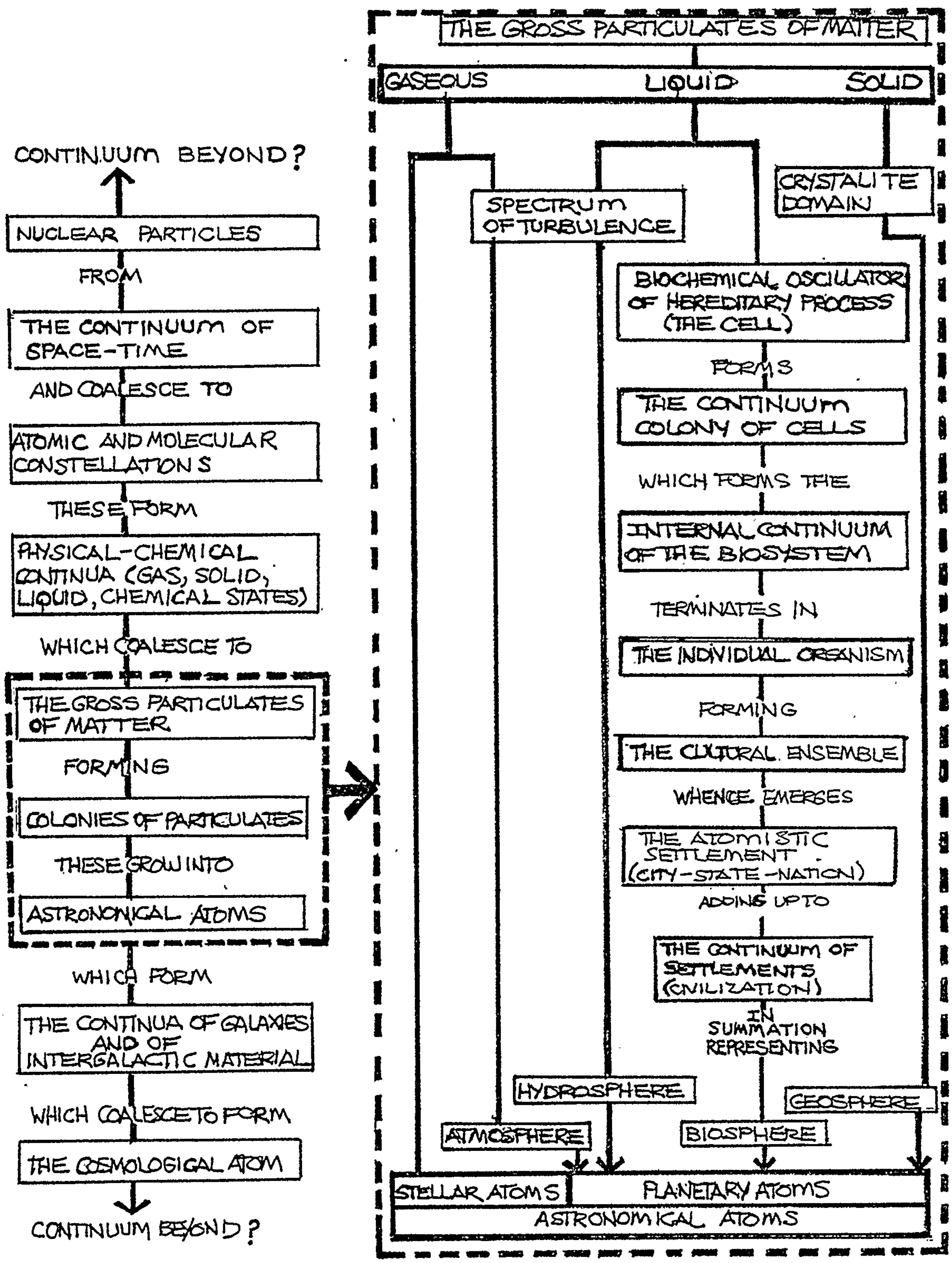


FIGURE 3
The Hierarchical Pattern of Organization Within The Reality Continuum
Source: Adapted from Iberall(1972)

of elements standing in interaction"; interaction implying some organizational relationship between elements. This definition identifies the necessary condition for establishing a general system construct. This condition is the presence of organizational relationships between the parts of a system. As previously stated in Section One, it is organization that distinguishes systems from aggregates.

A general system is an abstract conceptual construct, the 'anatomy' or structure of which (Chadwick, 1971) is composed of six elements:

i) A set of interacting elements or objects selected from the continuum of all possible interacting elements or objects.

ii) A set of attributes or properties exhibited by the elements of the selected set.

iii) A conceptual boundary condition around the selected set of elements. The boundary is conceptual in the sense that the boundary condition does not affect relationships between set elements and the rest of the continuum. Boundary selection is pragmatic (as is the selection of set elements); and is a function of set selection, in that the boundary distinguishes selected elements within the continuum.

iv) The 'environment' of set elements: This represents the set of all other possible sets of elements within the continuum not included with the selected set.

v) Possible subsets of elements within the selected set than can be distinguished by a set of unique organizational relationships between subset elements in addition to the relationships subset elements maintain with elements of the originally selected set.

vi) A set or sets of relationships postulated between;

- Elements of the selected set;
- The selected set as a whole and its subset(s);
- Two or more subsets;
- The selected set and its environment.

A diagram of the general system case is presented in Figure 4.

The general system is the basic unit of the systems concept. It is defined only by a set of organizational relationships between a group of elements selected from all possible elements and all possible relationships. Since there is no restriction on the nature of the elements or the numbers and types of possible relationships, a system, like reality, lies in the eye of the beholder (Chadwick, 1971). As a result, phenomena viewed by analogy to the general system concept can be defined as systems in an infinite number of possible ways, since the conceptual framework of reality (to which all phenomena belong) is that of a vast continuum of ordered relationships.

Applying the systems concept within this continuum requires discriminating a hierarchical level of ordered relationships for the specific set of relationships that are of interest as a system. This is necessary because the entire continuum can be viewed as a system, since all its parts are interrelated.

The selected set of elements of any system (other than the universal set of all possible elements in the continuum) are by definition part of the continuum. Therefore all selected sets of elements (including the universal set) represent some hierarchical level of ordered relationships from indefinitely small to indefinitely large.

This pattern of hierarchically ordered relationships that can be abstracted from the reality continuum is described by the first principle

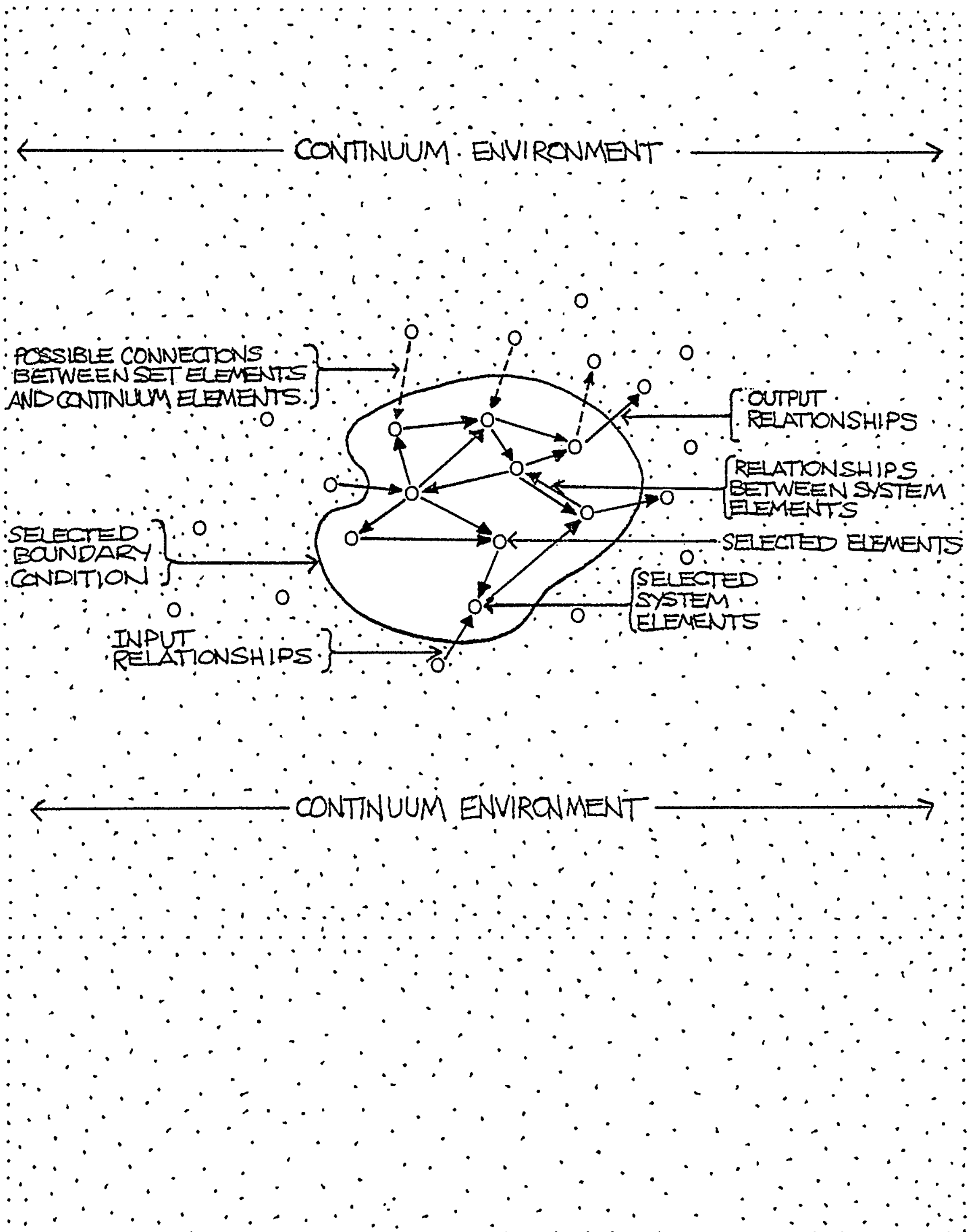


FIGURE 4
The General System Case
Source: Adapted from Chadwick (1972)

of systems science proposed by Iberall (1972). This pattern is described as an "...atom-continuum-atom-continuum..." or "A-C-A-C" sequence (Iberall, 1972). In this sequence, (illustrated in Figure 3, page 6 of this chapter) threshold levels occur with the increase of complexity (the number of possible connections or relationships between continuum elements) towards the indefinitely small as well as towards the indefinitely large ("indefinite" (Iberall, 1972) meaning; not without end but having an unknown end). These thresholds are termed "continuum" phases (Iberall, 1972) and represent levels of organizational complexity which function as integrated 'wholes' with properties unique to their level of complexity. The term "atom phases" (Iberall, 1972) refers to the less complex levels of organization that coalesce to form a more complex continuum phase either towards the indefinitely large or the indefinitely small.

This '...A-C-A-C...' organizational pattern is recursive since each hierarchical level of increasing complexity includes the preceeding continuum levels as basic components ('atoms') and in turn becomes a basic component of proceeding continuum levels. For example, a biological organism represents a hierarchical level of organization within the continuum that operates as a functioning whole (a "continuum" phase). The organism level includes lower order, less complex levels of organizations such as organs, cells, and genes. Each of these less complex organizational levels are functioning wholes in their own right, at some hierarchical level in the continuum, but become 'atom' phases at the organism level.

The A-C-A-C sequence is a 'system-subsystem-system' pattern of organization.

The recursive hierarchical pattern of organization operating within the reality continuum can be represented as follows (after Schultz, 1969):

(a)(b)(c)(d)(e)(f)(g)(h)(i)(j)(k)(l)(m)(n)(o)(p)
(a+b)(c+d)(e+f)(g+h)(i+j)(k+l)(m+n)(o+p)
(a+b+c+d)(e+f+g+h)(i+j+k+l)(m+n+o+p)
(a+b+c+d+e+f+g+h)(i+j+k+l+m+n+o+p)
(a+b+c+d+e+f+g+h+i+j+k+l+m+n+o+p)

— recursive hierarchical pattern of organization

This example illustrates the first principle of systems science as described by Iberall (1972) - any hierarchical level of organization within the continuum involves less complex hierarchical levels and is itself involved in organizational relationships of more complex hierarchical levels.

The general system case possesses 3 characteristics (Chadwick, 1971) in addition to the six component parts described earlier, that reflect its dynamic reality continuum context:

i) process,

ii) flow,

iii) input-output relationships

These characteristics are diagramatically represented below in Figure 5.

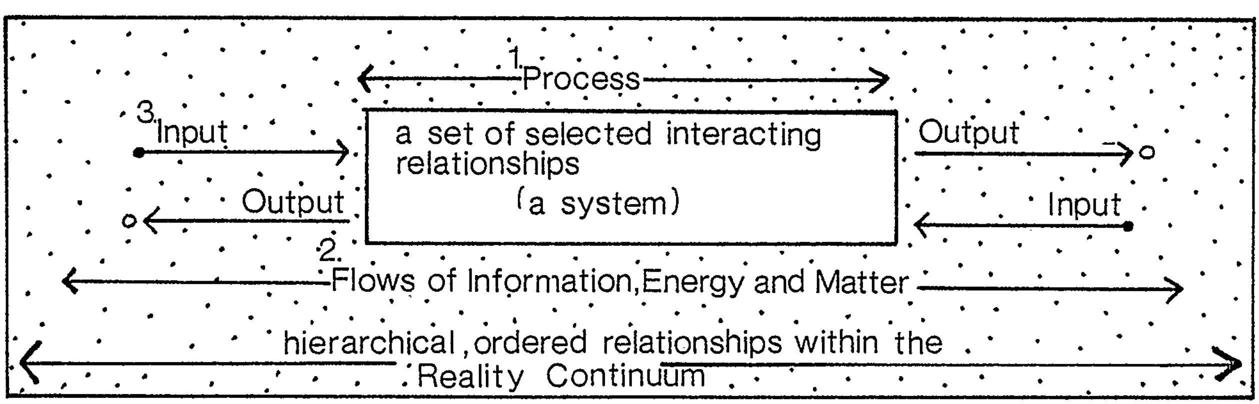


FIGURE 5
Three System Characteristics
Source: Adapted from Chadwick (1972)

These 3 general system characteristics (represented in Figure 5) operate in the same recursive hierarchical pattern that characterizes continuum organization. Process, flow, and input-output relationships can be identified and described at all levels of organization within a system: i) Process, is a dynamic sequence of changing organizational complexity (Chadwick, 1971). From less complex to more complex or vice versa. Within a system, processes occur:

- At the organizational level of the functioning whole system.
- Between a system and its continuum environment.
- Between subsystems.
- At the organizational level of a subsystem.
- Between system elements.
- At the organization level of a system element.

ii) Flow, is a specific type of process. Flows of information, energy, and matter occur within all systems regardless of type. For example, Chadwick (1971) describes flow in a perceptual system "...A group of people walking through and seeing a landscape, has as its basis a set of flows of information which relate to the flow of matter (people) and to flows of energy which they and the vegetation around them produce and consume..."

Flow relationships occur at and between the same organizational levels of a system described for process.

iii) Input-Output Relationships, express the rates and levels of change inherent in a system's dynamic process and flow characteristics for the same recursive hierarchical levels of organization identified for process and flow.

The general system case, is an abstract construct that can be represented by equally abstract mathematical symbols. The symbolic representation of a mathematical system is defined by Moore (1966) as "...the resultant of the application of logic to a set of elements, relations, and operations, the characteristics of which are described by a consistent (i.e. noncontradictory) set of postulates..." Since the general system concept involves elements, relationships, and operations, the characteristics of which are described by systems theory (a consistent logical-mathematical set of postulates), it can also be symbolically represented.

Such a mathematical representation, involving the components and characteristics of the general system case previously discussed, is presented by Klir and Valach (1967):

"...Let a_o be the environment of systems. Denote the Set A = $(a_1, a_2, \ldots, a_n)$ and Set B = $(a_o, a_1, \ldots, a_n)$

Thus Set A consists only of the elements a_1, a_2, ...a_n, of System S, whereas B includes not only these, but also the environment, regarded here as a separate element a_o.

Let every element of Set B be characterized by a set of input quantities. Let symbol $r_i j$ denote the manner in which the input quantities of element aj depend upon the output quantities of element a_i, which follows from the relationship between these quantities. The set of all $r_i j$ (i, j = 0, 1, ...n) will be denoted by R. We can then define a system by saying that every set S = A, R constitutes a system..."

SYSTEMS IN GENERAL AS FUNCTIONING WHOLES

Reality continuum phenomena conceived of as systems by analogy to the general system concept possess features and characteristics in addition to those of the general system construct. Eight features have been identified as characteristic of functioning whole systems and will be integrated into the following discussion. These 8 features are:

i) All systems are carriers of observable qualities

ii) All systems have state conditions

iii) All systems have organizational structure and behavior (Chadwick, 1971)

iv) All systems are dynamic constructs (Major, 1969; Chadwick, 1971)

v) All systems involve a recursive hierarchical pattern of organization (Iberall, 1972)

vi) All systems involve a 'Gestalt' or synergetic phenomenon (Laszlo, 1972)

vii) All systems possess certain non-varying aspects or invariances of organizational structure (Laszlo, 1972; Chadwick, 1971)

viii) All systems have properties of variety and entropy (Chadwick, 1971)

• System Observables and States

Science is concerned with understanding phenomena within the context of the reality continuum from indefinitely small to indefinitely large. The empirical basis for dealing with continuum phenomena (particularly at heuristic and phenomenological levels of explanation) involves their observation or perception by an observer, who is also part of the reality continuum.

In the continuum of logical reduction between description and explanation, observation and perception of a phenomenon is a logical prior step to the development of a more refined analytical level of explanation. The development of conceptual frameworks for viewing phenomena and theoretical constructs as tools for explaining phenomena, involve levels of logical reduction as well as degrees of perceptual refinement.

Once continuum phenomena satisfy the requirements of the general system construct and are conceived of as systems by analogy; the next level of logical reduction and perceptual refinement, is to specify the unique features and characteristics of the selected set as a system construct; for example, the specific nature of the process, flow, and input-output relationships inherent in all systems and the particular properties associated with the component parts of the system.

Margenau (1950) states "...An external object serves as a carrier of observable properties, such as size, color, smell, energy, angular momentum, and so forth...". Any construct, such as a system, which assumes essentially the same role as an external object, becomes a carrier of observable properties. These observable properties have an "adjectival" (Margenau, 1950) relationship to a system construct, in that they describe, or are adjectives of the construct. For example (Margenau, 1950), an unspecific descriptive phase such as "the blue flower", can be translated as "the flower has the color blue" although the meaning is the same, in the second statement possession or continued ownership of the adjective blue has been ascribed to the flower. If the flower is always observed as blue, the assignment of possession does not present a problem. However, if this flower is not always blue but is sometimes observed as red, yellow, or white, assigning a possessive relationship between the flower and a specific color would be false. A more correct statement in either instance would be "the flower is invested with an observable named color" (Margenau, 1950). An observable in this sense is an abstract quality which can be assigned to objects or constructs. Unless properties are relatively constant or invariable they must be assigned as observables, the values of which emerge through observation.

Observables that are constant with observation are "property-observables" (Margenau, 1950). Variable observable properties are "latent observables".

An example of latent observables is provided by high-energy physics experiments (discussed in Section One). The appearance of observable qualities of the experimental phenomenon take on different values on different occasions realtive to the observer's interaction. The position or qualities of a subatomic particle cannot be assigned as constants but only as a probabilities (consistent with Einstein's quantum theory). A system construct, like a flower, can carry an indefinite number of observable properties. However, a finite set of properties can be selected as necessary and sufficient conditions for identifying an observed phenomenon such as a flower or a system. For example, the set of criteria involved in the general system construct serves to identify phenomena with a one-to-one correspondence to these criteria as systems.

Although the exact quality of many, if not all, of these selected properties may change over time; a combination of specific qualities serves to describe the 'state' of a system (or flower) at a given time. The qualities of such properties can usually be measured and stated as values or numbers. Qualities that reach this level of reduction and refinement are termed "quantities" (Margenau, 1950).

In much the same way, certain abstract qualities or observables characteristically carried by certain objects/constructs or groups of objects/constructs cannot be reduced to a quantitative level of reduction, but they may have certain measurable properties associated with them.

Just as a flower cannot be measured, neither can certain observable qualities carried by a flower be measured. For example, biological life or 'living' cannot be measured, but certain processes associated with plant life such as rates and levels of photosynthesis and growth can be.

In the same sense, functioning whole systems are carriers of latent and/or property observables which may not be measurable or quantifiable per se, but can be represented by measurable processes or properties associated with the observable.

• <u>System Structure</u>

System structure means the pattern of organizational relationships internal to a system construct (Chadwick, 1971). As continuum phenomena, systems, and hence system structure, will reflect the hierarchical recursive pattern of continuum organization (previously discussed at the beginning of Chapter Two).

There is an important distinction between system structure and system state. As previously described (Margenau, 1950), the state of an object or construct, such as a system, is a combination of specific qualities at a specific time. A state condition is essentially static since it is only valid for the specific time the selected observables were in a specific condition. However, systems are dynamic constructs consistent with the nature of the reality continuum (a space-time continuum) from which they are selected. For example, a given state P at time t_1 differs from a return to state P at time t_2 because time is irreversible (Chadwick, 1971). This inherent property of irreversible change over time is reflected in the dynamic nature of functioning whole systems and their characteristic processes such as flow, and input-output relationships. A system's state or states therefore reflect some phase or condition of dynamic system process.

The organizational structure of a system is also dynamic, since organizational relationships change over time. However the state of a system can change over time without a corresponding change in a system's organizational structure.

To illustrate this point, consider any sports team as a system by analogy to the general system construct. A team involves organizational relationships between its members, but specific individual players may change from year to year, during a game, or during the playing season. Despite such changes through time the functional organizational relationships between positions will remain essentially the same. The organizational structure of the team can be maintained regardless of the changes in individual players. For example a hockey team will usually have 3 forward positions, 2 defence positions, and a goalie.

An indefinite number of state conditions can represent a system over time, but the system will still maintain a recognizable organizational structure unless the complexity and type of dynamic change over time is significant enough to change organizational relationships. These two levels of change, structural change, and state change, are analogous to phenotypical and genotypical genetic changes. Phenotypical change is a state change while genotypical change affects structure.

Figure 6 illustrates state changes over different time scales (annual, seasonal, and successional) for an ecological system.

An example of structural change in ecological systems is the effect of pollution (Woodwell, 1970). Specifically, introduced pesticides such as DDT alter organizational relationships between system components. The effects of DDT on food chain relationships and the resulting changes in trophic structure within a system are well documented (for example; Holling and Goldberg, 1971).

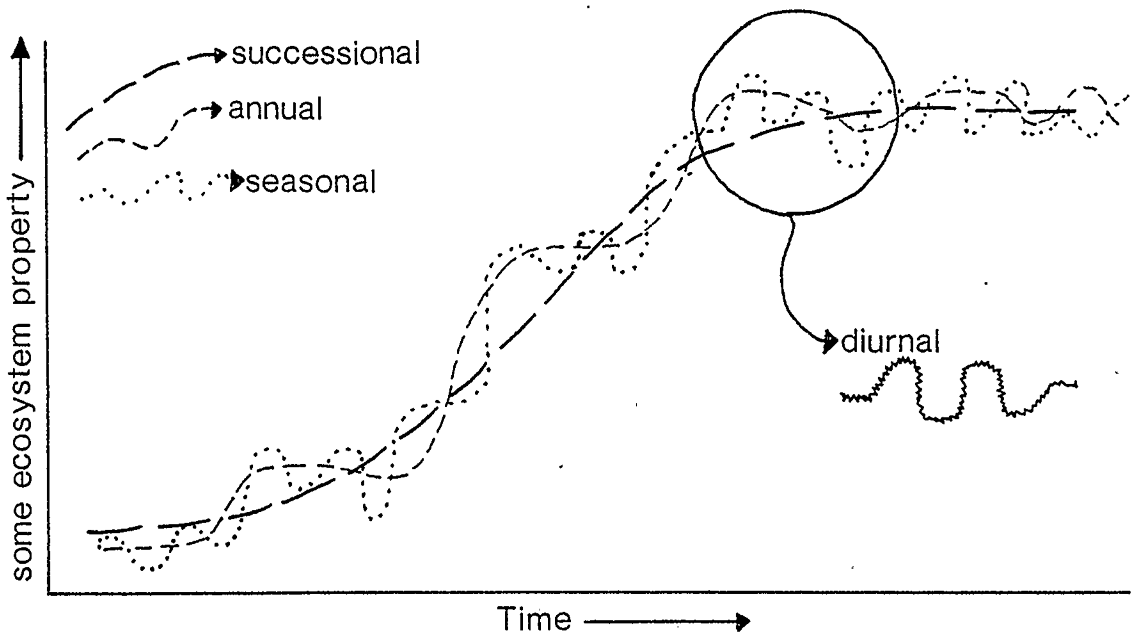


FIGURE 6
State Changes Over Time In An Ecological System
Source: Van Dyne (1969)

• System Behavior

System behavior refers to the response(s) of a system to changes both external and internal to its boundary condition (Holling, 1973).

This project has selected the following five factors as important contributors to system behavior:

i) The input-output relationships for the rates and levels of change for system processes over time.

ii) The Gestalt or synergetic property of functioning whole systems.

iii) The relationships and processes operating between a selected system construct and other levels of organization within its continuum environment (including other systems).

iv) The internal organizational (structural) relationships within a system construct.

v) The degree and complexity of variety and entropy within a system construct.

Selecting a system from the continuum involves assigning an arbitrary boundary condition to designate the set of relationships that are of interest as a system. However, both the designated system as a whole, and its elements and relationships still maintain their continuum relationships since a system's 'environment' is a component of a system construct. As a result, no system can be viewed as 'closed' to interactions with the continuum environment external to its boundary condition. All systems respond to some degree to conditions in their external environment.

External inputs of this nature (externalities) are important variables affecting system behavior at two levels of organization;

i) At the level of a functioning whole system.

ii) At hierarchical component levels within a system.

The input-output relationships characteristic of all system constructs express changes external and internal to a system construct over time. Input-output relationships exist for at least 3 basic levels of a systems organization structure;

i) The level of a functioning whole system

ii) The subsystem level

iii) The element level

System behavior is an internal response within a system's organizational structure (and state conditions thereof) to changing continuum conditions. The evolution or decay of a system reflects the internal organizational structure of its components.

The gestalt or synergetic principle of 'the whole being more than the sum of its parts' is reflected in the behavior of a system as a functioning whole. Just as the behavior of water in the external environment (for example, ice formation) cannot be understood only in terms of its hydrogen and oxygen components, the behavior of a system in response to external conditions cannot be fully understood from a knowledge of its component parts.

The occurrence of additional or 'emergent' properties at levels of increasing organizational complexity is termed the "principle of functional integration" (Fieblemen, 1954). The organizational basis of the gestalt phenomenon is referred to in Van Dyne's (1969) discussion of "the second dilemma". Essentially, as a number of objects increases, the probabilities of interactions between the objects increases proportionally to the square of the number of objects. This is consistent with the mathematical principles of permutation and combination (Moore, 1966) which recognize the increase in possible associations between objects as the number of objects increase.

At higher hierarchical levels of organization within a system (particularly at the systems level itself) there is an increase in the possible organizational relationships between components as a function of increased organizational complexity. A knowledge of organizational levels that are system components (and therefore less complex than the system itself) cannot provide an understanding of the system level as a functioning whole. The new or emergent relationships that occur at the system's level of organizational complexity do not exist at less complex component levels. Therefore the behavior of a functioning whole system will not be the same as the total behavior of its component parts.

System Types

The type of behavior characteristic of a system's organizational structure reflects the type of structure or pattern of organization present. A hierarchical classification of 4 general system types based on specific system characteristics and organizational patterns is presented by Boulding (1956). In order of increasing organizational complexity these 4 types are:

i) Static structure systems

ii) Simple dynamic systems

iii) Cybernetic systems

iv) Open systems

i) A static structure construct abstracts organizational relationships from a dynamic continuum phenomenon but treats the selected relationships as static cause and effect relationships. This type of system construct reflects a holistic (in that the concept of a functioning whole system is recognized), but mechanistic framework, similar to the static holistic principle of the Eleatic school of Greek thought (presented in Chapter One) and the static framework approach to the universe used by Galileo.

ii) A simple dynamic construct is a type of system involving predetermined necessary motions or relationships between components. Such 'mechanistic' systems are analogous to clockworks. They are dynamic constructs but their motion is cyclic, involving the indefinite repetition of a specific set of relationships (Iberall, 1972).

iii) Cybernetic system constructs require the dynamic flow of information and its interpretation within the system. The behavior of cybernetic systems is probabilistic rather than deterministic. These constructs are characterized by control functions involving information flow, interpretation, and feedback within the organizational structure of the system. The dynamic flow, interpretation, and feedback of information results in progressive system motion; meaning information from past and present system conditions will alter future conditions by changing or modifying organizational relationships, states, and related processes (Iberall, 1972). The cybernetic type of system is not self-maintaining. Rather, it functions at a subsystem level in a more complex system; the open system type. For example, the human brain as a system construct functions as a cybernetic system. On the basis of information flow, interpretation, and feedback, it exhibits control functions that regulate body states such as temperature. Although it is an important system in physiological homeostasis it is not self-maintaining; rather, it is a subsystem of the whole body system and is dependent upon other body subsystems such as the circulatory system for maintenance.

iv) The fourth and most complex type of system construct is the open system. Open systems are self-maintaining constructs characterized by probabilistic behavior and progressive motion involving cybernetic component levels of organization. Such systems are classified as 'open' because at least one integral internal component of system function is continually interacting with the construct's external continuum environment (Chadwick, 1971).

While the foregoing description of Boulding's (1956) classification of system types is useful, it does not clearly identify the relationship between increasing organizational complexity and emergent system behavior (introduced in the discussion of the organizational basis for systems gestalt). Further, Boulding's (1956) classification of the open system type is somewhat vague, since all systems are open to some extent to their external environment. In this regard, Beer's (1959) classification of systems types is preferred.

Beer's classification is based on two criteria; complexity (simple or complex) and determinism (deterministic or probabilistic). These criteria illustrate clearly the relationship between organizational complexity and behavior. For example, Chadwick (1971) states "...An electronic computer is complex but deterministic: it will only perform those operations that it has been programmed to carry out; tossing a penny on the other hand, may seem a simple system - and so it is, having only two states (i.e. a variety of 2) - but it can be described as probabilistic, being notoriously unpredictable in outcome in any one case..."

The 4 types of systems in Beer's (1959) classification (with an example of each type from Chadwick (1971) are:

i) Simple deterministic systems (clockworks)

ii) Complex deterministic systems (electronic computers)

iii) Simple probabilistic systems (a coin toss)

iv) Complex probabilistic systems (any ecological system construct)

The criteria of complexity used in Beer's (1959) classification of system types involves the principle of variety, identified previously (page 24, of this Chapter) as one of the 8 systems features, and can be described as follows.

• Variety

The variety of a system's organizational relationships (for example Chadwick's (1971) coin toss) is a measure of complexity. Variety is defined as "...The number of distinguishable elements within a set..." (Chadwick, 1971). However, variety is also dependent upon the number of possible interactions between each element of a set and every other set element. Thus a set with a small number of elements may have a high degree of variety or complexity if all elements are linked by two-way flow relationships. For example, Chadwick (1971) states "...Seven elements may have as many as 2^{42} or 1,000,000,000,000 different states if each of the elements is linked two ways with all its neighbors, and each link may be 'on' or 'off'."

Therefore variety, rather than size (in terms of numbers of elements within a system set), is the critical factor in determining the organizational complexity of a system construct. The variety of a system, because of its relationship to organizational structure, becomes an important factor in system behaviour since system processes (flows of information, energy, matter, and input-output relations) are consistent with the organizational complexity of relationships within a system.

• Complex Probabilistic Systems

The highest level or organizational complexity is represented by complex probabilistic type systems. Complex probabilistic system constructs involve phenomena toward both the indefinitely small and the indefinitely large portions of the reality continuum (for example; subatomic particles and the biosphere, respectively).

Complex probabilistic systems are of major importance to systems theory (Iberall, 1972) and systems analysis because:

- They involve a number of recursive hierarchical levels of organization in the 'A-C-A-C' organizational sequence characteristic of the reality continuum giving them a high degree of variety.
- They do not possess perfectly definable, measurable functional relationships and/or spatial links between their internal organizational components or between their internal components and their continuum environment.
- They continually undergo energy transformations and are not static.

For these reasons, plus the fact that complex probabilistic systems are natural systems (not man made but man influenced), the organizational structure, function, and behavior of this system type is of major concern to natural and physical sciences.

In addition to having the characteristics attributed to both cybernetic and open systems in Boulding's (1956) classification system, complex probabilistic systems are distinguished by two major features (Chadwick, 1971):

i) The importance of information flow to system function.

ii) Progressive motion of the system over time.

Information flow involves the transmission of a set or sets of messages from sources internal to the system or external to it. Information flow relationships can only exist between sending and receiving sources that have "structured variety" (Chadwick, 1971). This means the organizational pattern of components within the message source must be compatible with the organizational pattern of the receiving system. Since the organizational pattern of the reality continuum is replicated in the recursive hierarchical pattern of a system construct that represents (isomorphically) a continuum phenomenon, the internal organization of a system possesses structured variety with its continuum environment. As a result, information flow from the continuum environment can "trigger" (Chadwick, 1971) activity within a complex probabilistic system. Similarly information flow internal to the system at some level of organization can trigger activity within the whole system. Input-output relationships and flows of matter and energy also involve hierarchically structured relationships that become more complex with the increasing complexity of system organization (Chadwick, 1971).

The progressive motion of complex probabilistic systems over time is based on information flow and cybernetic system functions. The interpretation and feedback of dynamic flows of information energy and matter (from both past and present system states) results in future system changes in organizational structure, state, function and behavior.

Information flow in complex probabilistic systems involves variety and entropy. Variety has already been discussed as a measure of organizational complexity (page 24 of this chapter) and will appear again in the following discussion of entropy.

Entropy

Chadwick (1971) defines the concept of entropy as it is used in physics as a "...measure of the disbalance of energy in a system, it disorder, or randomness of organization...". As randomness and uncertainty increase with increasing entropy, instability increases within a system which will eventaully decay once a state of maximum entropy has been reached.

Given the assignment of equal probabilities to future system states, the principle of maximizing entropy gives the highest probability of occurrence to a future system state in which entropy is maximized, or randomness or organization is increased. In order to offset this theoretical trend to increasing disorganization and eventual instability and decay, complex prababilistic systems utilize information flow as a mechanism to offset or minimize entropy.

Information flow is inversely related to entropy (Chadwick(1971). For example, if a system is gaining in information, entropy is decreasing since information flow leads to increasing organizational complexity rather than disorder. Conversely, if a system is gaining in entropy, information flow is decreasing. In this sense information can be considered "negative entropy" (Chadwick(1971).

In general, progressive motion involving information flow, interpretation and feedback results in increasing organizational complexity (variety) as energy flow becomes increasingly organized or structured with decreasing entropy; subject to a threshold effect at which point energy flow within a mature system is insufficient to offset the trend of maximizing entropy and the system begins to decay. An example of this phenomenon is ecological succession. From the primary stage of succession organizational complexity (variety) increases and energy flow becomes increasingly organized towards the climax stage after which this mature stage begins to decay.

An example of this phenomenon is ecological succession. From the primary stage of succession organizational complexity (variety) increases and energy flow becomes increasingly organized towards the climax stage.

Organizational Invariances

Von Bertalanffy (1950) described general systems theory as "...The formulation and derivation of those principles which hold for systems in general..."

"Invariances" are non-varying aspects of the organizational structure of systems (Laszlo, 1972).

Chadwick (1971) describes three such conditions, involving organization relationships, and common to all systems:

i) Being - The presence of an organizational structure.

ii) Behaving - A process involving internal structural change over time.

iii) Becoming - A process involving irreversible reality continuum changes over time.

In addition to these 3 conditions, Laszlo (1972) has identified 4 invariances of natural systems (complex probabilistic systems) as functioning whole systems:

i) "Natural systems are wholes with irreducible properties", (the Gestalt phenomenon).

ii) "Natural systems maintain themselves in a changing environment", (Information flow, input-output relationships, and cybernetic control).

iii) "Natural systems create themselves in response to the challenge of the environment", (dynamic structural and state changes resulting from externalities and progressive motion).

iv) "Natural systems are co-ordinating interfaces in nature's hierarchy", (process, flows of information, energy, matter and input-output relationships within the internal hierarchical structure of a system construct and between the system construct and levels of organization in its continuum environment (including other systems).

Since these 4 invariances are common to all complex probabilistic systems they must not be ignored or violated in systems analysis.

PROBLEMS OF ANALYSIS FOR COMPLEX PROBABILISTIC SYSTEMS

By dictionary definition, analysis is "The breaking up of a whole into its parts to find out their nature". Analysis in the sense of this definition is consistent with an atomistic conceptual framework. Atomistic analysis, concerned with understanding component parts of a functioning whole, risks the danger of ignoring the importance of the functioning whole in an holistic sense. Both the gestalt phenomenon and Laszlo's (1972) first invariance of natural systems (functioning wholes with irreducible properties of their own) are denied by strict atomistic analysis. There is an atomistic tradition of analysis in Western science (inherited from Newtonian physics) still evident today in both the natural and social sciences. As stated in the proceedings o the social indicators conference (1975) sponsored by the Canada Council...

"The western analytic mind that finds out what things are by taking them apart has a difficult time dealing with the whole, particularly dealing with qualitative aspects of the whole".

Einstein's theories (discussed in Section One) exposed the limitations of the atomistic approach. They presented an empirically supported basis for viewing phenomena of the reality continuum as complex, probabilistic webs of relationships operating as dynamic interrelated wholes. The systems approach also conceives of such integrated wholes.. Within this framework, systems theory represents a body of rational knowledge resulting from the abstraction of common organizational features of integrated whole systems. The systems approach is concerned with integrated functioning wholes, not the mechanistic aggregation of parts in isolated causal relationships. An understanding of complex probabilistic systems cannot be achieved with atomistic/reductionist analysis in the same sense that atomistic Newtonian theory could not provide an understanding of subatomic phenomena.

Breaking down phenomenon within the reality continuum (which function as interconnected, interrelated, and interdependent wholes composed of complex webs of relationships and probabilities of relationships) by atomistic analysis risks treating such phenomena as mechanistic aggregates rather than systems.

Laszlo (1972) cautions...

"Scientific theories while simpler than reality must nevertheless reflect its essential structure. Science must be aware of rejecting the structure for the sake of simplicity, that would be to throw out the baby with the bathwater".

The systems approach has been presented (in Section One) as providing an integration of the holistic concern for the whole with an atomistic focus on parts within a framework concerned with the organizational relationships of parts in the context of functioning wholes.

Systems analysis must be consistent with this approach and encompass the organizational level of the whole system as well as its component levels of organization. This consistency must apply at all levels of explanation; heuristic, phenomenological, and analytic. As discussed previously, constructs are carriers of observable qualities that may become quantities if they are measurable (Margenau, 1950). But a system construct itself is not measurable. The concern for a system as a functioning whole inherent in a systems approach may involve dealing with qualitative aspects of the whole that are not measurable by traditional techniques of quantitative analysis.

There is a tendency in atomistic analysis to understand the parts of a whole in quantitative terms. The use of quantitative analysis (in ecology as well as other disciplines) is part of the strong influence of modern physics on Western science (Holling 1973).

Quantitative analysis reflects state conditions of a system construct since state conditions result from a specific combination of system observables (usually measurable) at a specific point or points in time. A quantitative evaluation of state conditions may not present an accurate picture of a system since only those observables that can be measured will become members of the set of properties that represent system state.

Observables carried by a system construct that reflect dynamic organizational relationships in complex probabilistic systems can be either expressed quantitatively with regression coefficients and ratios or treated at a qualitative level and expressed without numerical value. For example, isomorphic models (Schultz, 1969), represent a qualitative level of reduction at a phenomenological level of explanation. This type of descriptive model illustrates relationships and functional transformations between system components (Schultz, 1969). Figure 7 illustrates an isomorphic model. On the basis of isomorphic modelling, verbally expressible relationships can be established at the organizational level of the whole system from which more specific theorems can be developed. Schultz (1969) argues that numbers are superfluous to a sound conceptual understanding of a systems functional relationships at a qualitative level. For example, Andre Voisin's (Schultz 1969) definition of a grazing relationship is simply "cow meets grass".

Agreement at a qualitative level about important organizational relationships within functioning whole systems is an important and logical prior step to

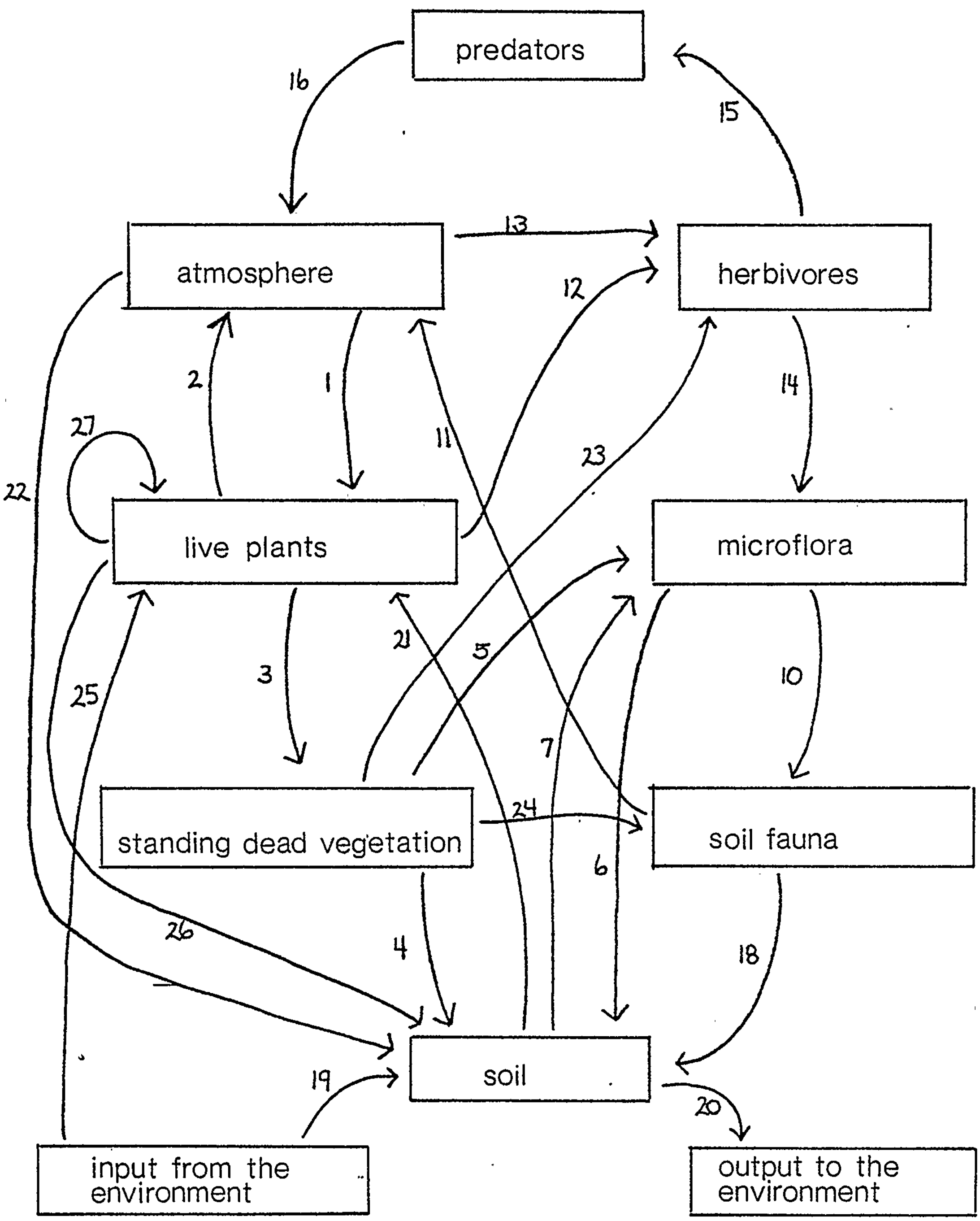


FIGURE 7
An Isomorphic Model Of Relationships Between System Elements.
Source: Adapted from Schultz (1969)

both quantitative analysis and the analytical level of explanation. This is particularly relevant in systems analysis since systems theory is an isomorphic construct (as discussed earlier).

The difficulties presented by complex probabilistic systems for quantitative atomistic analysis are based in the fact that such systems are composed of several hierarchical levels of organization and do not possess perfectly definable measurable relationships or spatial links. Complex probabilistic systems are carriers of latent or variable observable properties so that similar to subatomic phenomena, their states are highly probabilistic.

Complex probabilistic systems constructs can represent phenomena involving the indefinitely large and indefinitely small portions of the reality continuum which are not physically observable and may not behave in the same manner as phenomena in the zone of middle dimensions (for example, quantum behavior in subatomic phenomena).

Therefore, attempting to break down complex probabilistic systems into their component parts and relationships for quantification makes the task of atomistic analysis an incomplete and indefinite process.

McHarg (1977) states...

"We're still in the last stage of 19th century reductionism...anybody concerned with whole systems is just not respectable".

True systems analysis (consistent with the holistic and atomistic integration of the systems approach) requires an understanding of a construct's organizational relationships (structure) as well as state conditions of those relationships. It must deal with qualitative and quantitative levels of reduction for whole systems as well as their components and component levels of organization.

By placing equal emphasis on qualitative techniques, system analysis can deal with non-measurable observable qualities of functioning whole systems (for example a system's synergetic properties) usually ignored in atomistic quantitative analysis.

A detailed discussion of systems analysis in systems ecology will be presented later in Chapter Four.

LEXICON OF SYSTEMS DESCRIPTORS

The following lexicon is a summarization of the terms used throughout the text to describe systems. It is intended as a source of reference to the reader to assist in identifying terms referred to in following chapters.

It should be noted that the system descriptors summarized below are not internally consistent. This lack of consistency and the absence of a common or standardized systems vocabulary results in a myriad of systems descriptors and taxonomy presented by various authors which leads to confusion between the use of terms and their meanings.

Chapter Two:

1) Six elements of general system structure (Chadwick, 1971, p. 7):

i) A set of interactions elements selected from the continuum of all possible interacting elements.

ii) A set of attributes or properties exhibited by the elements of the selected sets.

iii) A conceptual boundary around the selected set of elements.

iv) The environment of the selected set, representing elements of the continuum not included in the selected set.

v) Subsets of elements within the selected set which have a unique organizational relationship among their elements.

vi) Sets of relationships postulated between:

- elements of the selected set;
- the selected set as a whole and its subset(s);
- two or more subsets;
- the selected set and its environment.

2) First principle of systems science (Iberall, 1972; page 9):

A pattern of recursive hierarchical organizational relationships that characterize the sequence of organization within the reality continuum towards both the indefinitely small and the indefinitely large. Indefinite meaning not without end but having an unknown end.

This principle is also referred to as the "A-C-A-C" sequence of continuum organization.

3) The three characteristics of the general system case (Chadwick, 1971; page 11):

i) Process (a dynamic sequence of change).

ii) Flows of information, energy, and matter (flows represent a specific type of process).

iii) Input-output relationships (express rates and levels of change in process and flow).

4) The eight features characterisitic of functioning whole systems; page 14):

i) All systems are carriers of observable qualities (Margenau, 1950).

ii) All systems have state changes over time (Margenau, 1950).

iii) All systems have dynamic organizational structure and behavior (Chadwick, 1971).

iv) All systems are dynamic (Major, 1969; Chadwick, 1971).

v) All systems involve a recursive hierarchical pattern of organization (Iberall, 1972).

vi) All systems have a gestalt or synergetic property (Laszlo, 1972).

vii) All systems possess certain non-varying aspects of invariances of organizational structure (Laszlo, 1972; Chadwick, 1971).

viii) All systems have properties of variety and entropy (Chadwich, 1971).

5) System observables (Margenau, 1950; page 15):

These are properties carried by a system construct that describe its qualities, for example, size, color, smell. There are two types of observables:

i) Property observables (properties that are constant with observation over time).

ii) Latent observables (properties that vary with observation over time).

6) System state (Margenau, 1950; page 16):

Some set or combination of measured observables that describe the condition of a system construct or its components at some point in time. A state condition is essentially static since it is only valid for the specific time the selected set of observables is in a specific condition.

7) System structure (Chadwick, 1971; page 17):

The dynamic organizational relationships internal to a system construct.

8) System behavior (Holling, 1973; page 20):

Refers to the response(s) of a system to changes both external to its boundary condition and internal to it.

9) Five factors involved in system behavior (page 20):

i) Input-output relationships for the rates and levels of change for system processes over time (flows of information, energy and matter).

ii) The gestalt or synergetic property of functioning whole systems.

iii) Relationships and processes operating between a selected construct and other levels of organization within its environment, including other systems.

iv) Internal structural relationships internal to a system construct.

v) The degree and complexity of variety and entropy within a system construct.

10) Boulding's (1956) classification of 4 system types (page 22):

i) Static Structure Systems - sets of static cause-and-effect relationships.

ii) Simple Dynamic Systems - involve the indefinite repetition of a specific set of relationships or cyclic motion.

iii) Cybernetic systems - system processes are probabilistic rather than deterministic (as is the case with static structure and simple dynamic system types). This system type involves the dynamic flow, interpretation and feedback of information. Cybernetic type systems are not self-maintaining and function as subsystems in more complex systems.

iv) Open Systems - are the most complex type of systems in this classification. They are probabilistic self-maintaining constructs that involve cybernetic functions. This system type is termed 'open' because at least one integral internal system component is in continual interaction with the construct's external environment.

11) Beer's (1959) classification of 4 system types (page 24):

Beer's classifications are based on two criteria; complexity and determinism:

i) Simple Deterministic Systems - have low variety and deterministic system relationships.

ii) Complex Deterministic Systems - have a high degree of variety and deterministic construct relationships.

iii) Simple Probabilistic Systems - have low variety and unpredictable relationships.

iv) Complex Probabilistic Systems - have a high degree of variety and progressive motion characterized by information flow, interpretation and feedback involving probabilistic relationships and processes.

12) System variety (Chadwick, 1971; page 25):

Refers to the complexity of a system construct dependent upon the number of possible interactions between system elements. Variety is not dependent on the 'size' of the system in terms of the number of elements. A set with a small number of elements can have a higher degree of variety than a system with a large number of elements if there is more interaction between elements.

13) Three characteristics of complex probabilistic systems important to systems analysis (Iberall, 1972; page 26):

i) They involve a number of recursive hierarchical levels of organization giving them a high degree of variety.

ii) They do not possess perfectly definable, measurable functional relationships and/or spatial links between their internal organizational components or between their internal components and their continuum environment.

iii) They continually undergo energy transformations and are not static.

14) Entropy (Chadwick, 1971; page 27):

Entropy is a measure or indicator of the disorganization of energy within a system. Information flow is inversely related to entropy; as information flow increases, entropy decreases and vice versa. Energy flow becomes increasingly organized or structured with decreasing entropy.

15) <u>Organizational invariances</u> (Laszlo, 1972; page 28):

Invariances are non-varying aspects of the organizational structure of systems.

a) Chadwick's three common conditions of all systems:

(i) <u>BEING</u> - the presence of an organizational structure.

(ii) <u>BEHAVING</u> - a process involving internal structural change over time.

(iii) <u>BECOMING</u> - a process involving irreversible reality continuum changes over time.

b) Laszlo's (1972) four invariances of complex probabilistic systems (Natural Systems):

In addition to Chadwick's (1971) conditions of being, behaving, and becoming, Laszlo has identified the following invariances:

(i) "Natural systems are wholes with irreducible properties."

(ii) "Natural systems maintain themselves in a changing environment."

(iii) "Natural systems create themselves in response to the challenge of the environment."

(iv) "Natural systems are co-ordinating interfaces in nature's hierarchy."

Chapter Three:

1) <u>Five factors in ecosystem behavior</u> (page 64):

i) Input-output relationships between the system and its environment as well as between component levels of system organization.

ii) The gestalt principle of functioning whole systems.

iii) Flows of energy, information and matter within the systems internal structure and between the system and its external environment.

iv) Conditions of variety and entropy within the system.

v) Invariances of structural organization.

2) Two major ecosystem behaviors (page 65):

i) Homeostasis - the ability of a system to re-establish a normal state following a disturbance.

ii) Maturation - a pattern of change in structure and function over time as a result of both ecological and evolutionary processes.

3) Two types of equilibrium conditions (Chadwick, 1971; page 66):

i) Stationary equilibrium - a return to a fixed point of balance after a disturbance.

ii) Dynamic equilibrium - a shift through or to a new condition of balance after a disturbance.

4) Two equilibrium field patterns (Holling and Goldberg, 1971; page 67):

i) Stable limit cycles - recursive sequences of stable points.

ii) Stable trajectory - a progressive rather than recursive sequence of stable points.

Chapter Four:

1) Four stages in systems analysis (Dale, 1970; page 70):

i) Lexical phase - selection (identification) and delimitation of components for a system construct.

ii) Parsing phase - identification and selection of relationships between components that are of interest for analysis.

iii) Modelling phase - mathematically specifying or representing the mechanisms by which the relationships selected in the parsing phase occur.

iv) Analysis phase - the mathematical solution of the model and validation of the model results by comparison to 'real world' system results.

2) Seven system characteristics important in macrosystem analysis (page 87):

i) Organizational structure involving complexity, variety, and entropy.

ii) System process, flows of information, energy, and matter.

iii) Input-output relationships.

iv) Exogenous variables.

v) System observables (both latent and property types).

vi) System motion.

vii) System behavior.

Chapter Five:

1) Four major components or subsystems of the man/nature system (Chadwick, 1971; page 4):

i) The Biosphere.

ii) Human value systems.

iii) Human activity systems.

iv) Human systems of adapted spaces (built environment).

CHAPTER THREE: NATURAL SYSTEMS AND ECOSYSTEMS

INTRODUCTION

The field of ecology (Collier, Cox, Johnson and Miller, 1973) is the study of interrelationships between organisms and their physical environment. It is concerned with understanding ecosystem structure, function and behavior (Johnson, 1977).

The systems concept involves a set of interacting, interrelated, and interdependent elements or objects operating as a functioning whole. Within the reality continuum, systems are identified or defined by analogy to a general system construct.

Ecological systems or 'ecosystems' are sets of interacting biological and physical elements which operate as functioning wholes at some hierarchical level of discrimination. Such sets of interacting biophysical elements can be very small in terms of spatial boundaries or very large, for example the biosphere itself. However, it is complexity in the sense of variety (discussed in Chapter Two) rather than spatial size that is the critical factor in understanding system structure and behavior.

Sets of interrelated biological and physical elements are also conceived of as systems or ecological systems by analogy to a general system construct. A system can then be further defined by analogy to the characteristcis of a particular type of system such as the complex probabilistic system type.

Conversely, on the basis of their correspondence to both a general system construct and a particular system type; several structural and behavioral characteristics can be assumed about the identified system. For example, the eight basic features of systems as functioning wholes (see page 14, Chapter Two). An ecosystem represents a theoretical system construct the components of which are interacting biological and physical elements selected from, and representative of, some hierarchical level or levels in the reality continuum. As such, the organization and function of ecosystems is consistent with the principles of systems theory and can be understood at a qualitative and/or quantitative level of reduction by applying the principles of systems theory and the systems approach.

THE ECOSYSTEM CONCEPT

The term "ecosystem" was first used by A. G. Tansley in 1935. Tansley's explanation of the ecosystem concept is presented in Smith (1976) as follows...

"The more fundamental conception is...the whole 'system' (in the sense of physics) including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment...we cannot separate them (the organisms) from their spatial environment with which they form one physical system...It is the systems so formed which...(are) the basic units of nature on the face of the earth...These 'ecosystems', as we may call them, are of the most various kinds and sizes."

Prior to Tansley's use of the word 'ecosystem' the concept of ecosystem (the interrelationships and interaction between organisms and the physical environment) had existed in some form since at least 6th Century B.C. in the dynamic holism of Heraclitus and the Milesian school of thought. In the biological sciences, Alexander von Humboldt, a plant geographer, presented essentially a systems view (Major, 1969) as early as 1807, stating..."In the great chain of causes and effects no thing and no activity should be regarded in isolation."

The science of ecology started to develop in the late 1800's and early 1900's as a descriptive field (Collier et al, 1974) primarily concerned with the identification of common biogeographic patterns and forms of different organisms in different environments. This phase was significant in the later development of systems thinking in contemporary ecology because it recognized the importance of the interactions between organisms and their physical environments. This initial descriptive phase represented a heuristic level of explanation.

As a developing science, ecology was heavily influenced by the atomistic and quantitative traditions of modern physics (Holling, 1973). Ecology moved from its initial descriptive qualitative phase to a quantitative level of reduction. Ecologists developed quantitative techniques to represent the taxonomic composition and structure of biological populations and communities. Areas of specialization developed within the field consistent with the increasing use of the atomistic approach to analysis, associated with the quantitative techniques inherited from Newtonian physics. Autecology; the study of a single species, and synecology; the study of communities, provided areas of detailed information easily dealt with by quantitative analysis. During this quantitative phase, the mathematical description of static elements took precedence over dynamic biological/physical environment relationships (Collier et al, 1973).

The development of the systems approach and formal systems theory (Von Bertalanffy, 1950) provided a conceptual and theoretical framework for abstracting relationships between objects and events within an organizational structure of an integrated, functioning whole. The emerging paradigm or pattern of systems thinking provided an alternative to the static mechanistic explanation of ecosystem function characteristic of isolated quantitative analysis of individual organisms, populations, communities and other ecosystem components.

Contemporary systems ecology is concerned with dynamic relationships and process for ecological system constructs as functioning wholes (Collier et al, 1973).

Systems thinking in contemporary ecology represents an integrated alternative which complements both the holistic and atomistic approaches of traditiona scientific thinking. It provides the emphasis on interrelationships lacking in the atomistic approach and an empirical body of theory lacking in the holistic approach. The development and application of the systems approach and systems theory in ecology is a logical and consistent extension of a conceptual framework that conceives of relationships between objects and events in terms of integrated wholes in a field that historically, and be definition, is concerned with interrelationships between organisms and their physical environment.

The importance of a systems approach in ecology is emphasized by Dansereau (1971)...

"It is not enough to say that ecology studies living organisms (including man) in relation to their environment. Ecology is not ecology unless it devises means to apprehend the full complexity of a given space occupied (temporarily or permanently) by living organisms (including man); unless it can give an account of the dynamic whole; and unless it can situate the parts in their true relationship with each other and with the whole."

This concern with the dynamic whole is basic to a systems approach. The features of general systems theory, previously discussed, (including; system gestalt, variety, the first principle of systems science, and system structure) are related to the functions Dansereau describes above as important consideration in ecology. For example, these relationships can be described as follows:

- The systems approach provides the "means" with which to understand the complexity of biological environmental interactions.

• Both Iberall's first principle of systems theory and the synergetic phenomenon are involved in providing an "account" of a dynamic whole at some hierarchical level of organization.

• In order to "situate the parts" of the whole in relationship to each other and to the whole itself; the organizational structure and characteristic processes of process, flow, and input-output relationships must be understood.

ECOSYSTEM STRUCTURE

In the same sense that the general system construct represents the basic unit of systems theory; the ecosystem concept is the basic unit of environmental study (Dansereau, 1971).

Establishing a theoretical construct for an ecological system requires consistency with both the conceptual framework and the principles of systems theory provided by the systems approach.

A set of biological and environmental interrelationships is conceived of as a system in the same way that any set of elements becomes a system; by analogy to the features and characteristics of a general system construct. Given Von Bertalanffy's (1950) original definition of a general system, "A complex of elements standing in interaction.", a set of biological and physical environment elements that interact with each other become a system in the general sense by this definition.

As a general system, such a set of elements will possess the components of the general system case (previously discussed in Chapter Two, page 7) in a one-to-one correspondence; such that:

i) A general system is a set of interacting elements selected from the reality continuum; An ecological system is a set of interacting biological and physical environment elements selected from the biosphere level of the ocntinuum.

ii) A general system includes the set of attributes or properties possessed by members of the system set; The biological and physical components of a selected ecological system set have unique attributes and observables (both latent and property types) dependent upon the climatic, geological and historical factors involved at a specific geographical location.

iii) A general system has a conceptual boundary condition that distinguishes the selected set of system elements within the reality continuum; Distinguishing a boundary condition for an ecological system is a function of both the "lexical" and "parsing" phases in systems ecology (Dale, 1970). The Lexical phase involves choosing system components. The parsing phase establishes relationships between the selected components. Establishing a boundary condition becomes a pragmatic process, since selecting the set of system components is affected by the relationships that are of concern for study.

iv) A general system includes the environment of its selected set of elements; An ecological system must also include reference to the elements, relationships, and processes of its external environment. Its set of elements is pragmatically selected from the reality continuum and is not isolated in any absolute sense. This reflects Iberall's first principle of systems science (recursive hierarchical levels of organization) and the fact that natural systems are complex probabilistic systems which are characteristically 'open'.

v) A general system has subsets or subsystems of elements within the system set that are distinguished by a unique set of organizational relationships yet still maintain relationships with the larger system set; An ecological system includes subsystems that reflect the recursive hierarchical pattern of organization characteristic of the reality continuum. For example, Odum's (1971) "Biological Spectrum" (Figure 8) illustrates hierarchical levels of organization within the biological continuum consistent with the first principle of systems science.

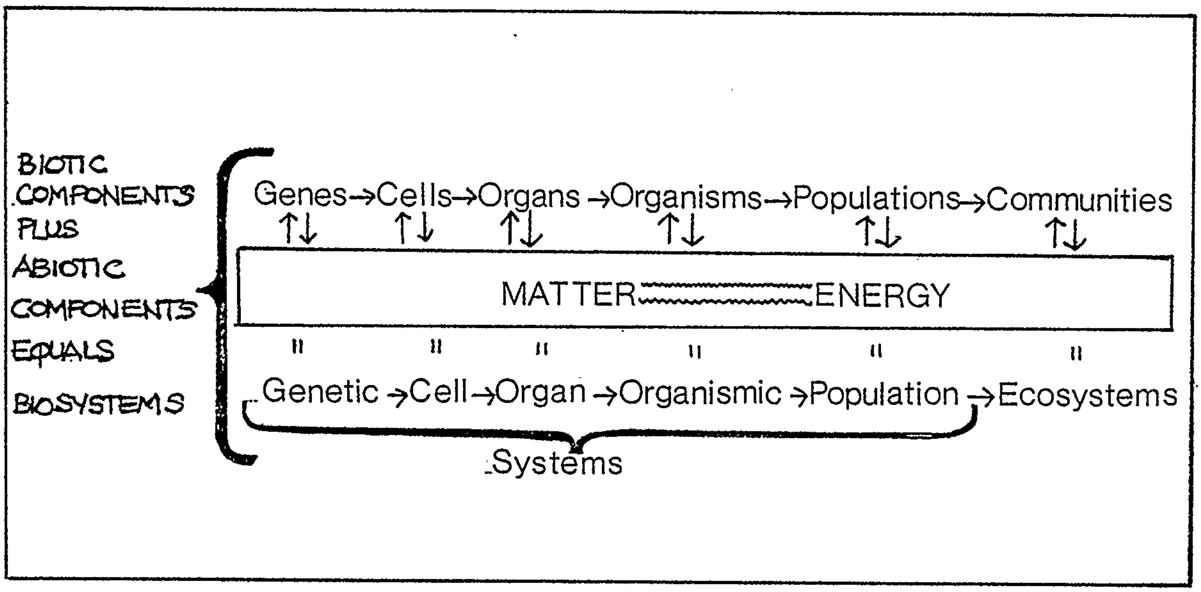


FIGURE 8
The Biological Spectrum
Source: Odum(1971)

The "A-C-A-C" sequence described by Iberall (1972) is illustrated by the hierarchical levels identified by Odum (1971) since each level is a component of the next higher level. A system at one level becomes a subsystem at higher levels. The organizational sequence illustrated by the biological spectrum can be extended along the continuum to include the biosphere as a system composed of ecosystems. At the biosphere level and possibly into the continuum beyond, ecosystems become subsystems, consistent with the recursive hierarchical levels of organization in the reality continuum.

vi) A general system includes sets of relationships postualted for and between hierarchical levels of organization within the system; Ecological systems involve processes, flows of information, energy, matter and input-output relationships between individuals, populations and communities within the system as well as between the system and levels of organization within the external environment (including other systems, and the biosphere).

The one-to-one correspondence between features of a general system construct and an ecosystem construct, just described, can be extended to include the three characterisitcs of the general system construct (Chapter Two, page 9

i) Process

ii) Flow of energy, information, and matter

iii) Input-output relationships

As in the case of the general system (page 5, Chapter Two), each of these characterisitcs appears in a recursive hierarchical pattern at different organizational levels within the ecosystem construct.

A simplified general diagram of an ecological system construct illustrating basic components and flow characteristics (Izard, 1972) is represented as follows in Figure 9.

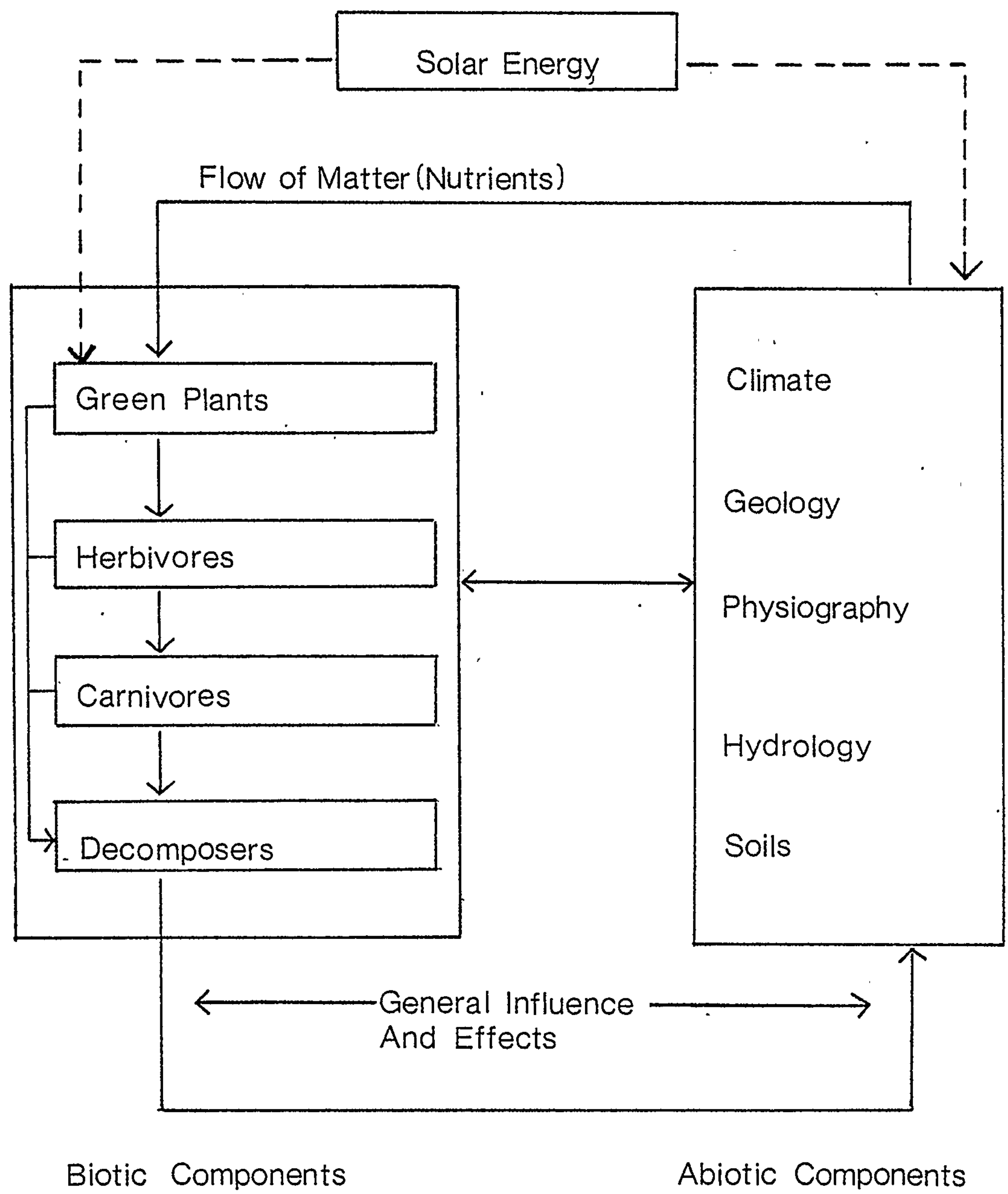


FIGURE 9
An Ecological System Construct
Source: Izard (1972)

The ecosystem concept as an abstract theoretical construct can be represented by mathematical symbols in the same sense as the general system construct. This is a function of ecosystem modelling in systems ecology.

Thus far an ecosystem has been treated as an abstract concept and as a theoretical construct by analogy to the general system case. However, ecologists have traditionally treated ecosystems as both a concept and as a spatial unit (Van Dyne, 1969).

The word "ecosystem" itself represents both; the interactions between biological organisms and their physical environment and; the concept of a system.

A primary concern for biological/physical environment interactions tends to place more emphasis on a spatial unit or geographical area. Both Evans (1956) and Odum (1971) have included the spatial unit emphasis in defining an ecosystem. For example, Odum (1971) states:

"Any unit that includes all of the organisms (i.e. community) 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 (i.e. exchange of materials between living and non-living parts) within the system is an ecological system or ecosystem."

The difficulty with this type of definition is that it presupposes:

- A knowledge about ecosystem structure involved in the concept of a system (trophic structure).
- That important system components can be bounded within a specific area.

As discussed earlier it is organizational relationships (including the concept of variety) that are the basis of a system, rather than spatial size.

The organizational pattern inherent in the systems concept can be applied to a dynamic set of relationships in any specific physical area but physical area does not necessarily define a system.

As stated earlier, systems in general (including ecological systems) do not exist in any absolute physical sense like a car or a building. As stated by Schultz (1969):

"The observer decides the level of organizational discrimination to be used in the study. He selects from the large number of possible relationships just those he wants to measure. He fixes the boundary of his system according to his resources and interests. Apart from the observer, there can be no unique ecosystem...The boundary is imaginary and is located at the convenience of the observer."

However, ecosystems, do have important biophysical factors that can be represented as spatial units, for example topographic watersheds as spatial unit boundaries for aquatic systems. However, such spatial boundaries correspond to specific system factors rather than a functioning whole system.

Jenny (Van Dyne, 1969) viewed ecological systems in terms of controlling and dependent factors. Controlling Factors include climate, geological materials, and available biotic organisms. Each controlling factor being composed of many system elements; for example, Jenny included parent material properties, relief, and ground water as elements of the geological materials factor. All three controlling factors operate in time, which although a controlling factor, is not considered an environmental factor. Controlling factors are synonymously termed "state factors" (Van Dyne, 1969) since they define by virtue of their control function, the condition of ecosystem observables at some point in time.

Dependent Factors, include soil, vegetation, consumer organisms, composer and transformer organisms, and microclimate (considered as the climate in which an organism lives). Jenny described dependent factors as dynamic and

and interdependent, representing the products of the interactions between controlling factors over time. Therefore, Jenny (Van Dyne, 1969) represented dependent factors as a function (f) of controlling or state factors: expressed as

$$l, s, v, a = f\ (Lo, Px, t)$$

where:

- 'l' is Ecosystem Properties
- 's' is Soil Properties
- 'v' is Vegetation Properties
- 'a' is Animal Properties
- 'Lo' is the initial state of the system (its properties at time zero when genesis starts)
- 'Px' is the flux potentials external to the system
- 'f' is the age of the system

Jenny's approach, as described above, involves both the concepts of an ecological system construct, and the ecosystem as a spatial unit, since changes in controlling factors in space and time produce corresponding changes in dependent ecosystem elements that are reflected in continuum and discrete spatial/physical boundaries and pattern or configuration; for example, ecotones, population gradients, and soil patterns.

ECOLOGICAL SYSTEMS AS FUNCTIONING WHOLES

Ecological systems represent a special case of the general system construct. They possess not only the features and characteristics of a general system but also demonstrate the eight identified features (Chapter Two, page 12) of all systems as functioning wholes in a one-to-one correspondence, such that ecosystems:

i) are carriers of observable properties

ii) have state conditoins

iii) have organizational structure and behavior

iv) are dynamic constructs

v) involve a recursive hierarchical pattern of organization

vi) involve a gestalt or synergetic phenomenon

vii) possess invariances of organizational structure

viii) have properties of variety and entropy

ECOSYSTEM STRUCTURE AND ORGANIZATION

The organizational relationships that constitute ecosystem structure are not static two-dimensional physically 'mappable' (in a spatial unit sense) interactions between components. They represent abstract conceptual approximations of phenomena that are beyond the range of sensory perception both in terms of scale and complexity. However, as is the case in high energy physics experiments, the physical after effects of such phenomena can be observed.

For example, the effects of "DDT" in functioning whole systems could not be physically observed as they occurred, but after a timelag upwards of 30 years (Holling and Goldberg, 1971), the physical effects of DDT on structural components of a system, such as the elimination of certain component species, were observable.

The conceptualization of a biological system's organizational structure involves four-dimensional abstraction which includes the variables of energy, matter, and space-time.

Ecosystem structure involves a recursive hierarchical pattern of organization described by the first principle of systems science. The biological spectrum illustrates that individuals, species, populations, and communities are subsystems at the ecosystem level but are also whole systems at less complex hierarchical levels. Each of these organizational levels are connected in a dynamic set or sets of relationships by; cyclic processes, flows of energy information, matter (involving variety and entropy) and input-output realtionships. Each of these processes operates in a hierarchical sequence, within and between system components, and between the system and its environment.

Ecological systems are natural systems (not man made, although man influenced). As natural systems, ecological systems are complex probabilistic type systems and therefore possess (by analogy) the features characteristic of this system type (described on page 25 of Chapter Two).

The major feature of complex probabilistic systems and hence ecosystems, is the importance of information flow (involving variety and entropy) in system function. Information flow is critical to the progressive motion of complex probabilistic systems, and hence natural ecological systems. As information increases, energy flow becomes increasingly organized and structured with decreasing entropy. In ecosystems, energy flow is the basic principle underlying their structure and function (Odum, 1976). Therefore information flow is directly involved in the behavior of ecological systems, since system behavior (Graham-Smith, 1972) involves its organizational structure.

Structural or organizational relationships within ecosystems become more complex (in terms of variety) at each increasing hierarchical level of organization from organism to community, to the ecosystem level itself. Flows of energy and information become more structured at each higher level of organization. As the system itself changes or evolves over time (through progressive motion) it tends to move toward more probable states of organizational structure. This phenomenon is reflected in trends of ecological succession in ecosystem maturation. Collier et al (1973) point out that young ecosystems or "pioneer" systems are characterized by unpredictable behavior and a high degree of external influence from input-output relationships with elements and/or relationships of the environment outside the system boundary. This "unpredictability" of systems in pioneer stages of succession corresponds to their high degree of entropy or the low degree of energy organization relative to the increased organization of energy relationships in mature stages. The increasing organizational complexity associated with the progression of successional stages, acts as a buffer to perturbations from the external environment. This provides more effective internal regulation of biogeochemical processes in mature stages relative to pioneer stages. As a result, mature systems exhibit more predictable behavior relative to immature systems. Decreasing entropy in maturing systems is related to increasing information consistent with the inverse relationship between information and energy. The increase of internal regulation in mature systems, as described above, is consistent with increasing information flow and the cybernetic functions of complex probabilistic systems. As a result, the behavior of mature ecosystems is characteristic of increasing information flow, interpretation and feedback in their organizational structure.

Consistent with the recursive hierarchical pattern of organization and information flow in complex probabilistic systems, ecological systems are subject to information triggers from higher and lower hierarchical levels of organization; particularly from the biosphere level. For example, extreme climatic fluctuations or conditions will significantly affect maturity, evolution and successional trends within an ecological system.

Lindeman's "pyramid" concept of energy flow in ecological systems (Smith, 1976), exemplifies the relationship between information flow and the increasing organization of energy within system structure just described. The pyramid concept is described by Smith (1976) as "...one of the cornerstones of ecology". It is based on the principle of increasing energy organization with ecosystem maturation and is described in the following discussion.

The Pyramid Concept of Structure and Energy Flow

Solar radiation is the source of energy for the biosphere and its component ecosystems. Energy flow from this source is not a constant or static input. The amount of solar radiation reaching the earth's surface varies daily, seasonally, and with topographic and geographic location.

The flows of energy within a selected set of biological and physical environment relationships begins with the fixation of radiant energy by green plants in the process of photosynthesis. Thermal radiation, in the form of heat, is also critical to biochemical events in this process over time. All of the radiant energy received by green plants is not fixed by photosynthesis, energy is lost at this stage through plant respiration. The energy 'fixed' by green plants forms a basis for further energy transfers within the set of components and relationships of the selected ecological system. The second stage occurs when consumer organisms feed on green plants and transform the available energy into animal tissue; again losing a portion of this energy through respiration and physiological maintenance.

At this second stage, energy fixed in consumer organisms and available for further transfer, is less than the amount of available energy produced by green plants. This transfer process continues through a variable number of stages including primary, secondary, and tertiary production and consumption. For example, primary producers (green plants) are eaten by secondary producers (herbivores) providing an available energy base for tertiary producers (first-level carnivores) which in turn provide energy for higher order consumers. As each transfer takes place, available energy is lost through incomplete food utilization and heat dissipation consistent with the second law of thermodynamics. This results in a smaller base of available energy at each successive transfer level. This pattern produces Lindeman's (1942) "pyramid" form of energy flow. With this decrease of available energy, the organization of energy flow within the system increases due to increased assimilation efficiencies of organisms toward the top of the pyramid (higher transfer stages).

However, this trend is not unlimited. The amount of energy lost at each transfer limits the number of feeding steps that can occur and hence the number of organisms that can be supported by the available energy base at each stage. For example, Smith (1976) states...

"Two-thirds to three-fourths of the energy stored by photosynthesis in a grassland ecosystem is returned to the soil as dead plant material, and less than one-fourth is consumed by herbivores, of this about one-half is returned to the soil as feces."

Waste products from each level, including dead and inedible plant material is termed "detritus". It is decomposed in a series of transfer stages between detritus-feeding organisms and bacteria constituting the reverse of the production process. The sequences of production/consumption, and decomposition, constitute the two major "food webs" (Smith, 1976) within the biotic components of all ecological systems. Ecological food webs are abstractions of feeding relationships between the biotic components of an ecosystem. "food chains" (Collier et al, 1973) refer to any linear sequence of species involved in feeding relationships within a food web. For example, within the food web of a tundra ecosystem, a linear food chain sequence might be;

plants -- ptarmigan -- arctic fox. However, the 'chain' is big at one end (plants) and small at the other (the fox population).

Trophic Structure

Within the energy pyramid concept, transfer stages of available energy represented by similar groups of producing and consuming organisms are called "trophic levels" (Collier et al, 1973). Trophic levels are ordered in terms of the number of transfer stages they are removed from primary producers. For example, primary producers are the first trophic level and secondary producers the second trophic level. This process may continue through second, third, and possibly fourth and fifth trophic levels.

Trophic levels are abstractions of the food web concept and not distinct physical or spatial entities (Collier et al, 1973). Species cannot be strictly classified as belonging only to a single trophic level. Many organisms (including man) have extremely varied diets or changes in diet that result in shifts from one trophic level to another. It therefore becomes extremely difficult to identify "a clearly defined trophic structure" for an ecosystem as Odum (1971) suggests in his ecosystem definition (previously presented on page 49 of this chapter).

A diagram of the general flow of energy through any ecological system illustrating trophic level relationships within Lindeman's (1942) pyramid structure is illustrated in Figure 10.

Three general characteristics of relationships between trophic levels illustrated by the energy pyramid concept are:

i) The flow of available energy is less at each succeeding trophic level.

ii) The efficiency of energy assimilation by organisms increases with each succeeding trophic level.

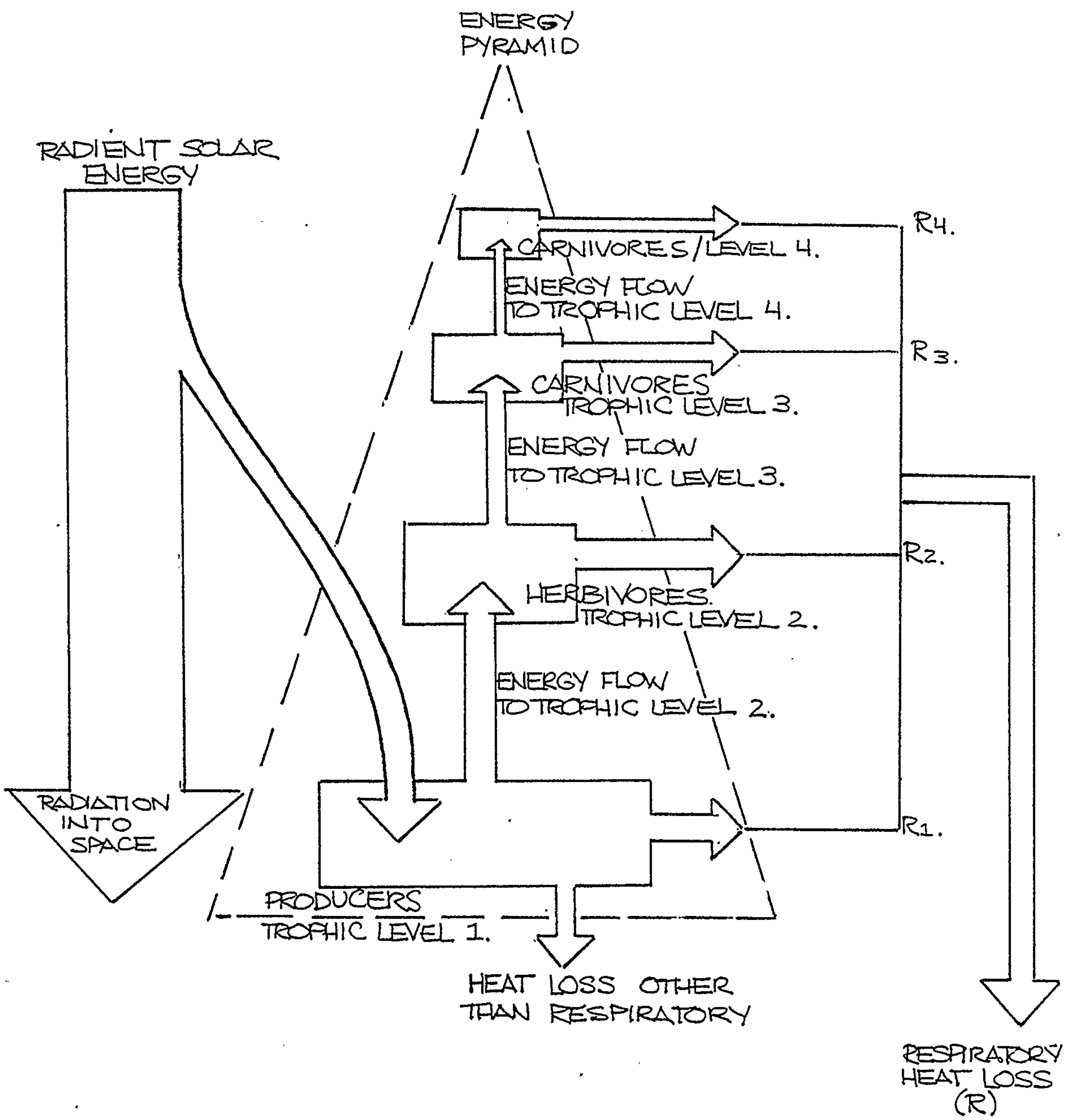


FIGURE 10
The Pyramid Concept Of Energy Flow And Trophic Structure
Source: Smith (1976)

iii) The rates of respiration in organisms at higher trophic levels increases proportionally with increasing efficiency in energy assimilation. This process maintains decreasing net production (gross production minus the respiration rate) and the system's pyramid structure since increased energy assimilation efficiencies are offset by increasing respiration rates.

Each of these three characteristics are consistent with the principles of entropy and information flow operating in complex probabilistic systems. For example, at each successive trophic level in mature ecosystems, energy assimilation is more efficient and therefore more ordered or structured; as a result, entropy decreases. However, just because mature systems have low entropy relative to immature systems, it does not necessarily follow that a high degree of trophic level development can always be associated with mature ecosystems. In this regard, external environment conditions (Jenny's controlling factors, page 50 of this chapter) such as relief and climate also affect trophic development. As a result mature tundra and alpine ecosystems have relatively few trophic levels or low trophic development.

Ecosystem Process

The three major characteristics inherent in the general system construct were presented (in Chapter Two) as: process; flows of information, energy, matter; and input-output relationships. In ecological system constructs, these three characteristics are critical to system structure, function and behavior.

Flows of matter in ecosystems involve abiotic as well as biotic components and are primarily nutrient or geochemical cycles that operate at a global or biospheric level of organization. As such, these cycles affect the input-output relationships between the external environment of a system and the selected set of biological/physical relationships within a system's boundary condition. Examples of important cycles affecting ecosystem function include water, oxygen, nitrogen, carbon, sulphur, calcium, phosphorous, and trace metals such as mercury (Collier et al: 1973).

Flows of energy, information, and matter involved in trophic structure, and geochemical cycling are organized within the recursive hierarchical structure of an ecosystem; consistent with the organization of the reality continuum. As a result, such flows occur within a system's organizational structure at; organism, species, population and community levels; as well as between the system as a dynamic whole and its external environment (including other systems).

The characterisitcs of process, flows of energy, matter, information, and input-output relationships within the pyramid concept of ecosystem structure is presented in Figures 11, 12, and 13.

As illustrated by Figure 11, abiotic resource components (air, light, heat, energy, water, soils and nutrients) interact with biotic components or agents (green plants, herbivores, carnivores, and decomposers). Flows of information, energy and matter take place at successive trophic and hierarchical levels of organization and reflect the processes characteristic of the three identified trophic regimes.

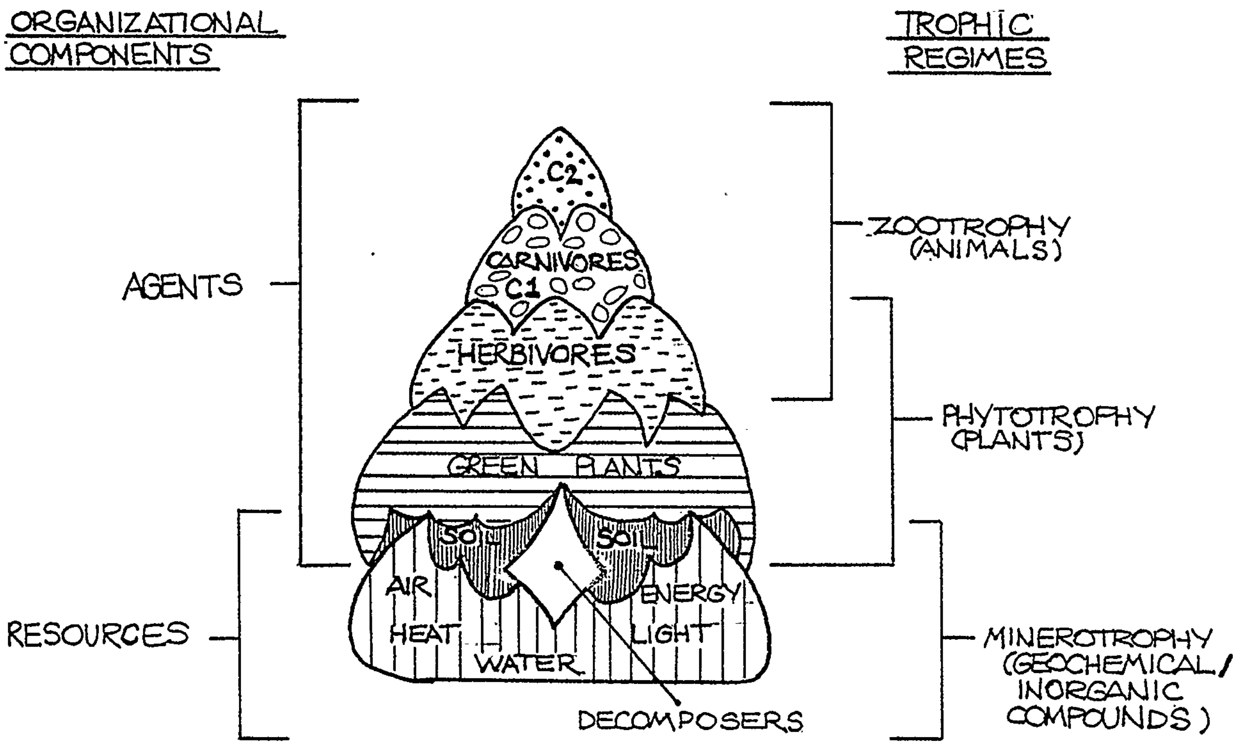


FIGURE 11
Organizational Components And Trophic Regimes
Source: Dansereau (1971)

Figure 12 illustrates the processes and trophic levels associated with the organizational components and three trophic regimes illustrated in Figure 11.

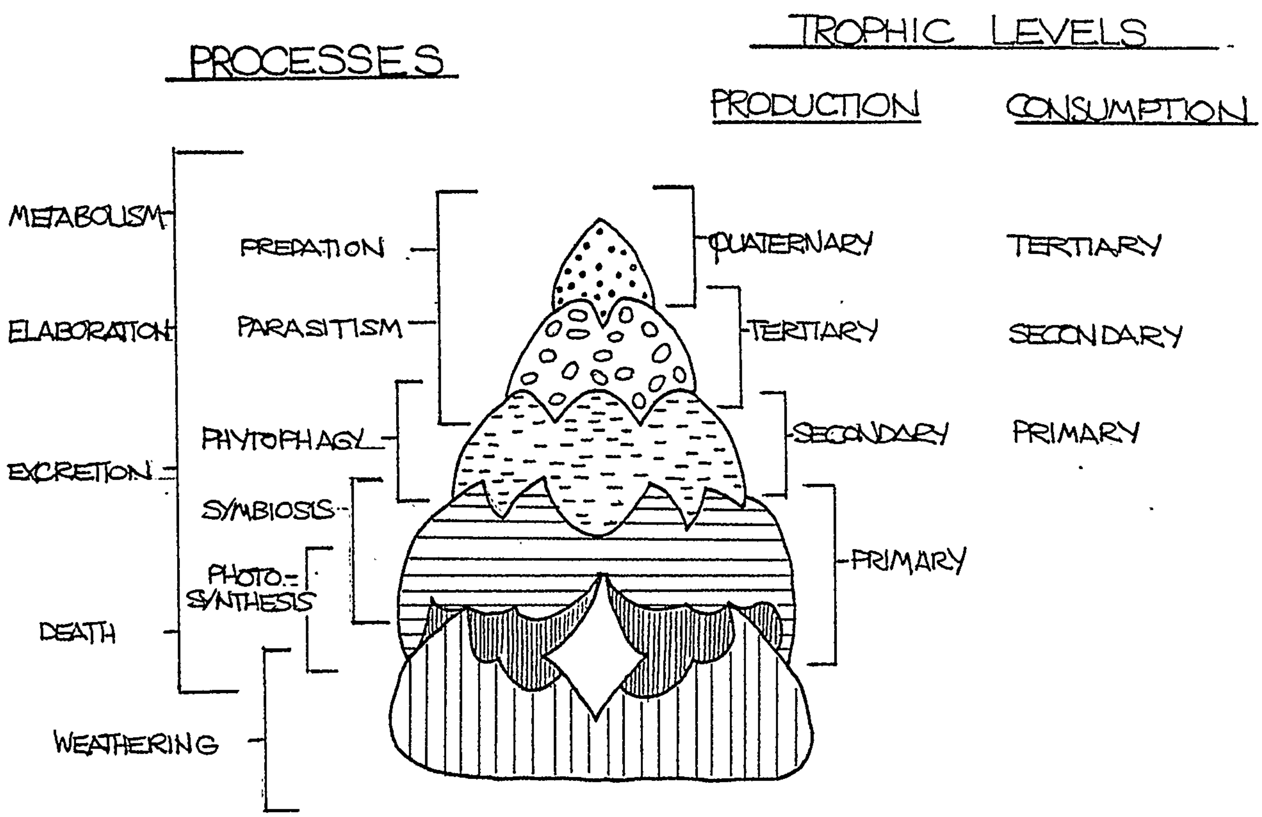


FIGURE 12
Process Involved In Trophic Structure
Source: Dansereau (1971)

Figure 13 illustrates input-output relationships for the rates and levels of change for process and flow within system structure.

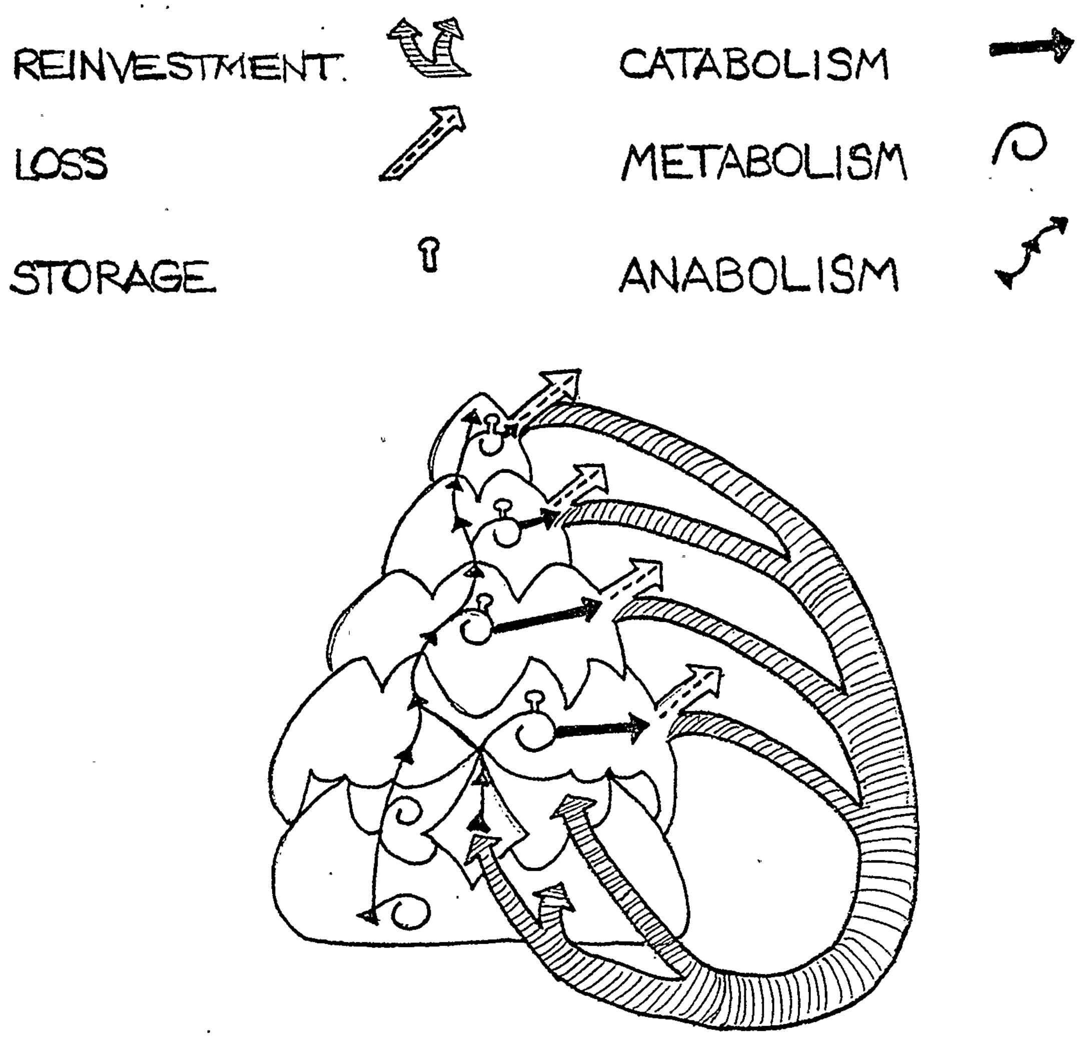


FIGURE 13
Input–Output Relationships Associated With Energy Transfer
Source: Dansereau (1971)

ECOSYSTEM BEHAVIOR

All system types possess the three conditions of being, behaving, and becoming (Chapter Two, page 28) and therefore apply to ecological systems.

As complex probabilistic systems characterized by progressive motion, ecosystems are constantly in a state of becoming; for example, successional changes in maturing ecological systems. Ecosystems undergo internal state and structural changes triggered by information flows from higher levels of organization external to the system (for example, the biosphere). Ecological systems have both open and cybernetic characteristics. As open systems, they receive continual inputs from external environment sources. The state conditions of the external variables involved in these input-output relationships can introduce external 'stress' into the system; for example, extreme climatic or nutrient flow fluctuations.

The cybernetic functions, of ecological systems attempt to manage such external inputs to reduce stress through homeostatic control; information flow, interpretation, and feedback.

External inputs affect system state and organizational structure at two levels:

i) The level of the functioning whole.

ii) The subsystem or component level.

The behavior of ecological systems is based on the same principles that affect the internal response and change of systems in general:

- organizational structure
- process, flow, and input-output characteristics

The following five factors have been selected as important in ecosystem behavior:

i) input-output relationships between the system and its environment as well as between component levels of system organization.

ii) the gestalt principle of functioning whole systems.

iii) flows of energy, information, and matter within the systems internal structure and between the system and its external environment.

iv) conditions of variety and entropy within the system construct.

v) invariances of structural organization.

Invariances of organizational structure are important correlates of system behavior since behavior reflects the state conditions and changes of a system's internal structure. This position is supported by a comparison of Laszlo's (1972) four invariances of natural systems with the two major ecosystem behaviors of homeostasis and maturation presented by Holling (1973) and Collier et al (1973).

Ecosystem homeostasis (Collier et al, 1973) is the ability of a system to re-establish a normal state following a disturbance. The behavior described by this definition is comparable to Laszlo's (1972) second invariance, "natural systems maintain themselves in a changing environment".

Ecosystem maturation (Collier et al, 1973) is a pattern of change in structure and function over time as a result of both ecological and evolutionary processes. The definition of this second behavior mirrors Laszlo's (1972) third invariance, "natural systems create themselves in response to the challenge of the environment".

Homeostasis (discussed in Chapter Two as a cybernetic function of complex probabilistic systems) is often termed "stability" (Holling, 1973). The stability concept of ecosystem behavior has retained an association with mathematical conditions near equilibrium. Two types of equilibrium conditions exist (Chadwick, 1971):

i) stationary equilibrium; a return to a fixed point of balance after a disturbance.

ii) dynamic equilibrium; a shift through or to a new condition of balance after a disturbance.

A stationary equilibrium view of stability is essentially a static concept and therefore inappropriate for describing ecosystem behavior. As complex probabilistic systems, ecosystems are characterized by progressive motion involving information from past system states and constant interaction and information flow with a dynamic external continuum environment. Holling and Goldberg (1971) state...

"Ecological systems are not in a state of delicate balance. Long before man appeared on the scene, natural systems were subjected to traumas and shocks imposed by climatic changes and other geophysical processes."

Stability behavior in ecological systems involves dynamic cybernetic control functions. Stability is not conditional on one static hypothetical equilibrium point. Ecosystem stability involves the concept of dynamic equilibrium encompassing several possible equilibrium points. Such an equilibrium field, or range of stable conditions, is referred to by Holling (1973) as a "domain of stability" or as a "domain of attraction" (the motion of a system being attracted to positions of equilibrium). The limit to which system qualities can be perturbed and still return over time to a position in a dynamic equilibrium field is termed "the boundary of stability" (Holling and Goldberg, 1971).

The stability behavior of a system is an important strategy in determining future state and structural conditions. For example, Holling and Goldberg (1971) state...

"Ecological systems exist in a highly variable physical environment so that the equilibrium point itself is constantly shifting and changing over time...because of this variability imposed upon ecological systems, the ones that have survived, the ones that have not exceeded the boundaries of stability are those that have evolved tactics to keep the domain of stability, or resilience, broad enough to absorb the consequences of change."

Two different equilibrium field patterns are identified by Holling and Goldberg (1971) for domains of stability in ecological systems;

i) stable limit cycles; recursive sequences of stable points.

ii) stable trajectory; a progressive rather than recursive sequence of stable points.

Stability behavior, as a homeostatic function, reflects the constancy of state conditions within the internal organizational structure of a system. Holling (1973) defines "stability" as the return of a system to an equilibrium <u>state</u> rather than a single point (fixed or otherwise) after a <u>temporary</u> disturbance.

However, the constant interaction of ecological systems with their external environment introduces climatic, geophysical, and cultural (land use) variables that place continual environmental stress on internal organizational relationships and their states. This <u>constant</u> rather than temporary stress, places more emphasis on the ability of a system's structural relationships to persist over time than on the constancy of its internal state conditions.

Holling (1973) correlates maturation (the pattern of change in structure and function over time resulting from both ecological and evolutionary processes) identified earlier as the second major ecosystem behavior with his theory of "resilience".

Resilience is concerned with system structure rather than state (the concern of stability).

Resilience is defined (Holling, 1973) as a behavioral property of ecological systems that reflects the ability of a system's organizational structure to absorb or assimilate external environment changes.

As complex probabilistic systems undergoing progressive motion, resilience behavior in ecological systems becomes important in understanding system function over time. For example, Holling (1973) states...

"Different and useful insights might be obtained by viewing the behavior of ecological systems in terms of the probability of extinction of their elements and by shifting emphasis from equilibrium states to conditions for persistence."

In Section One, the underlying feature of the systems concept was identified as organization rather than aggregation. In Chapter Two, Von Bertalanffy's basic definition of a system construct was presented as any group or set of elements standing in interaction and therefore possessing organizational relationships. In both instances, organizational structure is a critical factor in the systems concept. Therefore resilience, as a behavioral property of ecological systems involving organizational structure, is an important factor in a systems approach to understanding ecosystem function over time.

System state(s) represent specific conditions of organizational structure that reflect a system construct's inherent characteristics of process, flow, and input-output relationships (both internal to the system and between the system and its external environment) at some point in time. As illustrated in the sports team example (Chapter Two), state conditions can change frequently within a constant organizational structure. <u>It is structure</u>,

<u>rather than state, that is critical to the persistence of a system construct as an identifiable functioning entity</u>.

A change in organizational structure, therefore, becomes more important to the persistance of a system over time than simply how stable its state conditions are within a specific structural configuration.

A change in organizational structure can result in a change of a system's domain of stability. Holling (1973) identifies an important consideration in dealing with ecosystem behavior as; the probability of a system moving from one domain of stability (or attraction) to a new domain and its ability to persist within such a changed configuration.

For example, pollution can induce a structural change within freshwater lake ecosystems significantly altering process, flow, and input-output relationships. If this external stress is extreme or long term, the system may be pushed from one domain of stability to another.

The resilience of an ecological system to stress from the external environment (with which it constantly interacts) places an important emphasis on factors external to the system (externalities) rather than the constancy or stability of its internal state conditions.

CHAPTER FOUR: ECOSYSTEM ANALYSIS

INTRODUCTION

Systems ecology involves the application of the systems approach (as a conceptual framework and as a body of theory) to the study of dynamic interrelationships between structure and function in ecological systems (Collier et al, 1973).

The primary goal in systems ecology is most often the development of predictive mathematical models intended to represent the processes and organizational relationships involved in the structure and function of ecological systems (Collier et al, 1973; Morales, 1974; Dale, 1972). The process used to develop such system models in ecology is systems analysis. Dale (1972) defines systems analysis as...

"...the application of scientific method to complex problems, and this application is further distinguished by the use of advanced mathematical and statistical techniques and by the use of computers."

The goal of producing mathematical models through the process of systems analysis has placed the current emphasis of systems ecology on the use of quantitative techniques. This emphasis can be seen in Dale's (1970) definition of four stages for systems analysis, described below:

i) "the lexical phase"; selection (identification) and delimitation of components for a system construct.

ii) "the parsing phase"; identification and selection of relationships between components that are of interest for analysis.

iii) "the modelling phase"; mathematically specifying or representing the mechanisms by which the relationships selected in the parsing phase occur.

iv) "the analysis phase"; includes the mathematical solution of the model, validation of model results by comparison to 'real' system results, and the investigation and identification of the model's functioning properties.

The danger in equating the application of the systems approach in ecology with the quantitative techniques used in the modelling and analysis phases is the likely elimination of important system characteristics which do not fit a quantitative approach. For example, Margenau (1950) identifies the level of reduction between abstract qualities (observables) and measurable quantities (discussed in Chapter Two). Certain qualities carried by a system construct can be reduced to quantities but others, such as system gestalt, cannot be measured per se.

Without a consideration of the qualitative aspects of systems theory (isomorphic by previous definition) a situation in systems ecology can result in which:

- only those system properties that are measurable (in a parametric sense) become part of the system model.
- the mathematically plausible is assumed to be ecologically necessary (Slobodkin, 1974).
- what is mathematically solvable is regarded as ecologically probable (Slobodkin, 1974).
- the conceptually possible (for example, Holling's stability and resilience theory of ecosystem behavior) is considered biologically "real" and therefore measurable (Morales, 1974).
- mathematical models are conceived as "mirrors of reality" rather than phenomenological or heuristic constructs (Morales, 1974).

Van Dyne (1969) identifies 3 categories of "tools" for problem-solving in ecology;

i) conceptual and/or methodological

ii) mechanical

iii) mathematical

The conceptual aspects of problem-solving should not be disgarded in favor of mathematical (and associated mechanical) tools. For example, Morales (1974) states...

"Science needs to be self-conscious about more than the relative effectiveness or fit of that equation or this model. It has to be self-aware of the ontological and epistemological presuppositions and consequences of its techniques and theoretical approaches."

Collier et al (1973) suggest that the future direction of ecology "centers on the concept of ecosystem." This includes applying the framework, abstractions, and theoretical constructs inherent in the systems approach which may not fit quantitative techniques of analysis.

If ecology is to give an account of ecological systems as dynamic wholes (Dansereau, 1971), the ability of quantitative techniques and data in providing such an account must be evaluated. Diamond (1974) suggests that theoretical conclusions drawn from quantitative data gathered from different levels of organization within a system does not necessarily reflect the function or behavior of a system as a whole. For example the collection of quantitative data for developing energy and nutrient flow models of ecological systems is of little value in understanding the structure and behavior of functioning whole systems interacting with the external environment. Diamond (1974) states...

"Despite the intensive effort and experimentation required to accumulate such vital and comprehensive data, these models do not analyze the structure of a system itself...rather, such energy and nutrient budgets serve as sources of kinetic data in our attempts to understand the dynamic characteristics of biological systems."

Energy and nutrient flows within a selected set of relationships defining an ecosystem result from cycles operating at a global or biosphere level of organization and are not simply an internal function within a system.

Other quantitative measures of specific functions or processes can also be misleading in terms of understanding the whole system. One of the most important of these measures is the quantitative evaluation of productivity (the amount of organic matter created by photosynthesis within a system's trophic structure). Major (1969) describes the quantitative assessment of productivity as a "...simplifying measure which can ignore the ecosystem idea and which then gives the same numbers for Death Valley as for the northernmost coast of Alaska."

Quantitative data or "quantities" (as defined previously by Margeneau, 1950) represent a level of logical reduction for observable qualities carried by a construct. Each level of reduction in the continuum from description to explanation acts as a logical prior step to further levels of reduction or detail. For example, just as modelling precedes the analysis phase and the lexical and parsing phases logically precede modelling in systems analysis and the heuristic and phenomenological levels of reduction precede the analytical level of explanation; the observation or perception of qualitative observables carried by a system construct precedes their reduction to quantities.

Attempting to deal with phenomena (as constructs) at the more detailed or refined levels of reduction (such as; the modelling/analysis phases of systems analysis; the analytical level of explanation; and the quantity level of observable qualities) requires an understanding of the framework provided by preceding levels of reduction. In the case of the modelling and analysis phases in systems analysis, a qualitative understanding of prior heuristic (lexical phase) and phenomenological (parsing phase) levels of reduction are important (as a logical prior stage) in the development of quantitative analytic models. As such, it provides a framework for understanding the logical relationships between levels of reduction. If discrepancies then appear between levels of reduction or explanation, this framework can be used in recasting models and their assumptions, or in re-examining the way quantitative data was collected and interpreted. For example, Diamond (1974) states...

"It might be argued that is is better to begin with a general model whose assumptions and biological relations are "right" despite a lack of detailed numerical data which varies according to locality."

This type of approach is consistent with systems thinking since systems theory is a body of isomorphic constructs concerned with organizational relationships. The type of general model alluded to in Diamond's statement is also isomorphic in that it is concerned with identifying and describing component relationships within a system construct.

MODELLING AND ANALYSIS IN SYSTEMS ECOLOGY

The use of quantitative techniques in systems ecology is associated with the modelling phase and its associated analysis process. Both phases correspond to Iberall's (1972) analytic level of formal explanation. The model represents the elements, relationships, and functions, of a selected system in an abstract (mathematical) form which can be pragmatically manipulated in the analysis phase (which includes the mathematical solution of the model) without reference back to the original field of physical phenomena.

The development of such a model (as a theoretical construct) should be consistent with the information provided by preceding levels of explanation as well as the theoretical principles that operate for the type of system being modelled. In modelling and analysis techniques for dynamic ecological systems (complex probabilistic type systems) this is not always the case.

In addition to the problems associated with the dominant use of quantitative techniques in systems analysis, three potential problems related to the modelling and analysis phases are identified as follows:

i) the assumption of cause and effect relationships for changes in component and system states over time.

ii) the inclusion in the model of only those elements and relationships internal to the systems boundary condition (and measurable).

iii) basing the mathematical solution of a model on state conditions of observables at component levels of organization below that of the whole system.

To varying degrees, in each of the above problem situations, certain principles of complex probabilistic systems and organizational relationships established at an isomorphic level of explanation (particularly the inputs and flows of information, energy, and matter, from the external continuum environment) are denied. For example, Rosen (1972) argues that the dynamics of complex probabilistic systems are not operationally determinable if a model's solution is based exclusively on changes in component state conditions. Rosen (1972) identifies two common procedures in current modelling techniques that form the basis for a model's mathematical solution and the analysis of a system's dynamic and temporal properties. These two factors are:

i) the selection of appropriate state variables.

ii) the determination of dynamic laws of motion equations which express rates of change in individual state variables as a function of that state.

Symbolically, any state variable or set of state variables can be designated as...

$Xi\ (X_1 \ldots X_n)$

Any equation that expresses rates of change for state variables can be represented by a numerically valued function (f) defined by the state values of system or component variables.

The numerical function (f) represents a quantity for which a measuring apparatus will measure (f) for any state ($X^o 1 \ldots X^o n$) measured by the apparatus.

This functional value is represented as...

$f\ (X^o 1 \ldots X^o n)$

The equation expressing rates of change in individual state variables as a function of that state can be represented as...

$$\frac{dxi}{dt} = f_i\ (X_1 \ldots X_n)$$

Such that the change of some state variable (dx_i) over some time (dt) is a function (fi) of the state of that variable ($X_1 \ldots X_n$) (x_i corresponding to Jenny's dependent variables Chapter Three, page 50).

However, progressive motion in complex probabilistic systems involves the past history of the system and its state conditions and not simply the state at the time of measurement (designated t_o). Yet the derivative $dx_i/_{dt}$ is placed initially at time t_o so that a change of state is assumed to be based directly on the state condition existing at time t_o and does not include the influence of past states (designated as $t < t_o$).

Rosen (1972) contends that the dynamics of a complex probabilistic system cannot be predicted from the quantitative evaluation of individual states (x_i) at time t_o. Attempting to predict future states on the basis of present states as a quantitative function of a select measurable group of system components assumes a cause-effect relationship. The only factor assumed to affect a future state condition is the present state condition. This is a deterministic view of a complex probabilistic phenomena that does not adequately take into account:

- external environmental influences outside a system's selected boundary condition.
- the effects of the organizational structure of the whole system as a dynamic entity on state conditions and therefore state change (for example progressive motion and maturation in ecological systems).

Measuring a selected set of system observables (either property or latent types) to establish a state condition at a specific point or points in time for a complex deterministic system, does not address the dynamics of the whole system. Rosen (1972) makes a distinction between state conditions which are static (representing a specific condition at a specific point or points in time) and the dynamic progressive motion of the whole system over time. In most modelling techniques (Rosen, 1972) dynamic equations of motion that act as driving parameters in the solution of the model (prediction of future state conditions) are represented by general theoretical principles, usually Newtonian laws of motion or mass action.

The use of these principles as driving parameters in models of complex probabilistic ecological systems (characterized by progressive motion) perpetuates a cause and effect, Newtonian view. However, probabilistic (unpredictable) systems do not operate by deterministic (predictable) laws.

Einstein's theories, particularly quantum theory (discussed in Section One) dealt with the behavior of probabilistic systems toward the indefinitely small end of the organizational continuum. At this level of reduction, phenomena are highly probabilistic. The conceptual and theoretical recognition of the quantum phenomenon in subatomic systems was not the result of quantative evaluation of system observables. As stated previously, the technological developments in high energy physics that enabled the properties of subatomic systems to be observed and measured did not occur until approximately 30 years after quantum theory and quantum mechanics had been proposed. Theoretical work in physics and astrophysics (Iberall, 1972) suggests the quantum issue may be equally valid in indefinitely large systems (such as the universe) which lie outside the Newtonian zone of middle dimensions; beyond the range of sensory perception.

Ecological systems, particularly at the organizational level of the biosphere, tend toward the indefinitely large end of the continuum and are 'open' to information flow from higher and lower levels of organization. At this scale, ecological systems, as functioning wholes, are also beyond the range of sensory perception although certain component levels of their organization operate in the zone of middle dimensions. In this respect, ecological systems may possess both classical and quantum properties. Holling's (1973) use of the domain of stability and domain of attraction concepts correspond to Iberall's (1972) description of behavior for subatomic systems with non-linear structural configurations in which the quantum issue arises. For example, Iberall (1972) states...

"There are processes governed by a hierarchy of higher frequency relations by which the system jumps from one stable non-linear state to others. The stability epochs between jumps mark domains in which the systems solutions may be described by convergent perturbations. This pattern results in a conceptual configuration of system motion as a vortex or helical shape."

Holling's (1973) concept of stability also involves "jumps" from one domain of stability to another and non-linear patterns for the trajectories of system motion. Holling also describes a domain of attraction as a vortex-like pattern that results from the frequency and amplitude of cyclic system processes (similar to Iberall's higher frequency relations) and the configuration of forces associated with homeostatic feedback relationships (also involved with perturbations in complex probabilistic systems).

The analysis of theoretic-quantum models for systems with mixed classical and quantum properties (Rosen, 1972) has shown that the conditions or "operator" that determine the dynamic equations of motion that drive the whole system are not necessarily system observables. Yet the modelling procedure criticized by Rosen (1972), is based on state conditions of measurable system observables at organizational levels below that of the whole system and represents system motion by classical Newtonian laws.

Hypothetically, systems ecology and its techniques of analysis are dealing with complex probabilistic systems that:

- tend toward the indefinitely large in terms of variety and complexity.
- are characterized by probabilistic progressive motion of the whole system.
- may involve the quantum issue as functioning wholes in that the function of the whole system is unpredictable in comparison to individual components which may be predictable.

In this case, system models based on state conditions of selected system observables and Newtonian laws of motion may be of limited value in attempting to understand ecological systems as functioning wholes

The second problem identified for the modelling phase (and hence its analysis) is the tendency to include only measurable endogenous (internal) system variables in the model. In Chapter Two the components of the general system construct included the 'environment' of selected system elements.

A system's environment represents all possible sets of elements within the continuum (including other systems) outside the conceptual boundary condition of a selected system construct.

All properties carried by the components of a selected construct are "endogenous" variables (Dale, 1970). In this sense, endogenous variables are the same as Jenny's dependent factors described in Chapter Three (page 50). Variables within the environment of the system are "exogenous" (Dale, 1970) and correspond to Jenny's controlling or state factors (Chapter Three, page 50).

Endogenous variables constitute the state description of a system over time while exogenous variables affect the relationships between internal components (endogenous variables) but are not properties carried by a system construct (Dale, 1970). As previously described in Chapters Two and Three, the behavior of complex probabilistic systems reflects the dynamic interaction between external and internal conditions. Therefore, in attempting to model organizational relationships for analysis, the interactions of a system's endogenous (internal) variables with exogenous (external) variables within its environment, are extremely important to system function and should not be ignored.

The tendency to build general models of ecological systems that consider only a system's internal relationships (Vincent, Pulliam, and Everett, 1974) resembles the isolated, small-scale, closed, laboratory approach in science that has often been criticized for its failure to deal with "real world" conditions. Since ecological systems are large-scale, open, complex probabilistic systems, involving flows of information, energy, and matter from its external environment; the interactions between endogenous and exogenous variables must by included in a model of system relationships.

The predominance of endogenous variables in modelling originates in the lexical and parsing phases of system analysis. The lexical phase involves selecting a set of system components. Dale (1970) defines the function of the parsing phase as the identification and/or choice of relationships between selected system components that are of interest for analysis. The conceptual boundary condition of a system is established around the set of selected system components to delineate them from all other elements within the reality continuum. Therefore, the set of elements selected in the lexical phase are internal system components. If the parsing phase by definition (Dale, 1970) then selects or identifies relationships that occur between the selected set of internal system components; then only relationships between endogenous variables will be identified.

Modelling the relationships between endogenous variables identified in the parsing phase represents the relationships occurring within a system's boundary condition in isolation from its external environment. This creates a misleading, 'closed' view of internal system function. For example, a model of a river system that includes only a river's internal hydrodynamic forces, ignores the effects of external conditions such as; topography, vegetation, soil type, and land use, on the dynamics of a river system which includes its internal hydrodynamic forces (Iberall, 1972).

The behavior of ecological systems (as discussed in Chapter Three) is profoundly affected by random external perturbations that can trigger extreme oscillations or change in both state conditions and structural relationships. Holling (1973) has postulated that severe perturbations (in terms of frequency and amplitude) can move a system from one domain of stability to another.

A unique example of the role of external perturbations in the stability behavior of ecological systems is Odum's (1971) concept of "pulse stability". In a pulse stabilized condition, an ecological system is affected by a somewhat regular but extreme external environment perturbation. Two common examples of this type of perturbation are:

i) Daily tidal effects in marine environments.

ii) Seasonal water level fluctuation in marsh and fresh water lake environments.

Ecological systems that are pulse stabilized contain internal components and component relationships that have adapted to a particular frequency and intensity of perturbation. The development of pulse stability within a system (usually in a long term or evolutionary time frame) illustrates the interaction between endogenous and exogenous variables.

Thus, the influence of exogenous variables in a system's external environment on its selected set of internal components and relationships should not be underestimated or ignored in the parsing and modelling phases of analysis for ecological systems.

The two potential problems of modelling and analysis just discussed, are part of a larger issue; that of basing the mathematical solution of a model on state conditions of property or latent observables for component levels of organization below that of the whole system.

As stated previously (Chapters Two and Three), the organizational structure of an ecological system can be analyzed at several hierarchical levels of organization consistent with the first principle of systems science. The analysis of any one of these less complex subsystem levels is necessarily incomplete in terms of understanding the whole system, just as the analysis of hydrogen and/or oxygen falls short of providing an understanding of the behavior of water. Subsystem or "microsystems" analysis (Kerr, 1974) is unavoidable subject to unanticipated emergent phenomena at the whole system or "macrosystem" level of organization. As pointed out previously in the discussion of Van Dyne's (1969) second dilemma, Iberall's (1972) first principle of systems science, and Laszlo's (1972) description of system gestalt in Chapter Two; properties emerge at higher levels of organization, which are not present at lower organizational levels, as a result of increasing complexity and variety with increasing organization that allows for more and different relationships between components.

The use of quantitative techniques in the modelling/analysis process makes dealing with the level of the whole system difficult since the system itself cannot be measured (Margenau, 1950). Breaking down the whole into its components may simplify measurement procedures (that correspond to component state conditions) but does not provide a framework for viewing components in the context of a functioning whole with its own unique characteristics related to variety and complexity of a system's organizational structure. Rosen's (1972) argument that the motion of whole systems is a characteristic unique to a macrosystem level of organization that cannot be determined from "microsystem" analysis of selected component state conditions is well taken; to attempt to understand the functioning of whole systems in relationship to their external environment variables on the basis of analysis at levels of organization below that of the system risks assuming that the whole is the sum of its parts.

The Role of Systems Analysis

One of the functions of the analysis phase is the validation of the results from a model's mathematical solution by comparison to "real system" results (Dale, 1970). This procedure illustrates the potential problem of viewing mathematical models as "mirrors of reality" (Morales, 1974), rather than as theoretical constructs. This problem is a central issue in clarifying the role or function of systems analysis in systems ecology.

Morales (1974) argues that ecosystem models are conceptual/theoretical constructs, representing abstract approximations of phenomena within the reality continuum. Rather than being "mirrors of reality", models and the modelling/analysis process more accurately mirrors the mind of the modeller (Henderson, 1975).

Conceptual frameworks (discussed previously in Section One) are abstract approximations of reality which can be represented symbolically. There is a tendency (Capra, 1975) to confuse reality with the symbols and concepts of our perceived or abstract approximations of reality. Since the way in which reality phenomena are conceived to occur relates directly to the way they are analyzed, the process of analysis is also prone to confusion between analyzing representative symbols of abstract approximations of a reality phenomenon and the reality phenomenon itself. For example, Morales (1974) states...

"Are stability and discontinuity a property of ecosystems or ecology? Are processes optimized on paper or in nature? Is a perturbation perturbing you or the system you study?"

Without this perspective, there is a tendency in the modelling/analysis process for systems ecologists (Levin, 1974) to create mathematical abstractions that formalize their perceptions and insights. These models then become 'real' entities in their own right from which "predictions" (defined by Chadwick, 1971 as a non-probabilistic statement on an absolute confidence level about the future) can be made for some perceived ecological system. This approach to modelling risks equating what is mathematically solvable with what must be ecologically necessary (Slobodkin, 1974).

The most frequent criticism of ecosystem models is their lack of 'realism' or their failure to'mirror' reality. Ecological models cannot be criticized or defended as ontologically true or false (Morales, 1974). To do so implies that ecosystem models reflect the essence of a system in reality. As theoretical constructs models only represent abstract approximations of reality and can only be evaluated in terms of their epistemological usefulness (Morales, 1974) within the limits, validity, and nature, of rational knowledge which is itself based on abstraction. For example, understanding and evaluating the modelling process in terms of what conceptual or theoretical direction a model will lead to and recognizing what implications it may have for developing better approximations of 'real' systems is a more valuable conceptual approach than a single minded concern with what a model or equation represents in reality. Viewing the systems analysis process as an important conceptual tool is preferable to confusing models with reality. Morales (1974) identifies the function of systems analysis in systems ecology as providing theoretical directions that will lead to better approximations of ecological system functions. This position contrasts sharply with the quantitative, true or false empiricism underlying the analytic "mirror of reality" approach in modelling. One of the potential problems associated with an exclusive quantitative approach is treating the conceptually possible as biologically "real" and therefore measurable. For example, concepts such as Holling's (1973) theory of resiliency is qualitative, and not amenable to quantitative analytic treatment. However, quantitative levels of reduction based on the theoretical direction provided by qualitative theories can result. For example, Innis (1974) has developed an initial quantitative treatment for part of Holling's (1973) qualitative theory.

Iberall's (1972) three levels of formal explanation (presented in Chapter Two) are; heuristic, phenomenological, and causal. Each level is associated with a particular model type; homomorphic (heuristic); isomorphic (phenomenological); and analytic (causal). Heuristic and phenomenological levels of explanation and their associated model types represent a qualitative level of reduction. The causal level of explanation and its analytic models represent a quantitative level of reduction.

The importance of heuristic and phenomenological (isomorphic) levels of explanation have been underestimated as sources of conceptual information prior to the development of quantitative analytic models (which represent the causal level explanation and logical reduction). Diamond (1974) argues that it may be better to begin with general models whose assumptions and relationships are accurate (isomorphic models), despite a lack of detailed numerical data (that will vary according to geographic location); in order to understand ecological system constructs as functioning wholes. Diamond's concern with establishing organizational relationships prior to obtaining quantitative data points out the value of phenomenological explanation and isomorphic models as logical prior steps to a quantitative level of reduction.

To function effectively as a conceptual tool in systems ecology, systems analysis can and should provide information at both qualitative and quantitative levels of explanation and modelling.

The systems concept and the systems approach are based on relationships (either abstract or empirical) between things or events. The basic concept in systems thinking is the organizational pattern or structure created by the relationships between system components. Systems are integrated functioning wholes, not mechanistic aggregates or parts. The systems concept of integrated functioning wholes must not be overwhelmed by the process of analysis (defined earlier as the breaking up of a whole into its parts to find out their nature). Just as the systems approach provides an integrated complement to both the holistic and atomistic approaches in scientific thinking; systems analysis must also provide an integrated but complementary alternative to quantitative atomistic analysis in systems ecology.

The logical difficulties of attempting to operationally determine the dynamics of functioning whole ecosystems (identified by Rosen, 1972) using state conditions of system components below the organization level of the whole system illustrates the importance of dealing with the organizational structure (and properties such as system motion) for functioning whole systems.

Ideally, macrosystem analysis in systems ecology should take into account the following 7 characteristics and features of functioning whole ecological systems (that are applicable at the level of the whole system) at an isomorphic as well as a causal analytical level of reduction:

i) organizational structure involving complexity, variety, and entropy.

ii) system process, flows of information, energy and matter.

iii) input-output relationships.

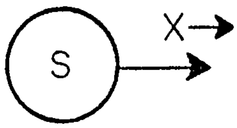
iv) exogenous variables.

v) system observables (both latent and property types).

vi) system motion.

vii) system behavior.

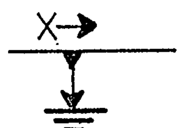
A technique of analysis currently being developed in systems ecology that fits into the type of alternative approach to systems analysis just described, is Howard T. Odum's (1974) use of "visual systems mathematics". This technique uses non-numeric symbolic language to develop diagrammatic system models that represent processes involved in a system's organizational relationships. These symbols and diagrammatic configurations illustrate the same information as equations and matrices, but are more easily understood because they represent concepts visually.



$$X = f(s)$$

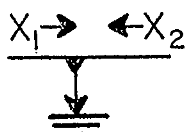
- External energy source (s) delivers forcing function (x) to a pathway.

- Heat sink indicates entropy increase with energy dispersal to environment.



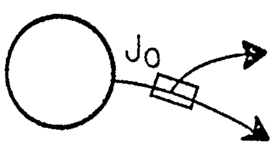
$$J = \frac{1}{R} X$$

- Normal pathway with flux (J) driven by force (x) opposed by frictional, dissipative backforce.



$$J = \frac{1}{R}(X_1 - X_2)$$

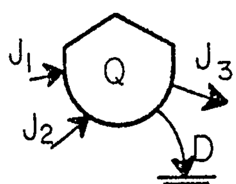
- Same but with backforce from downstream energy storage (x_2).



$$J = kR$$

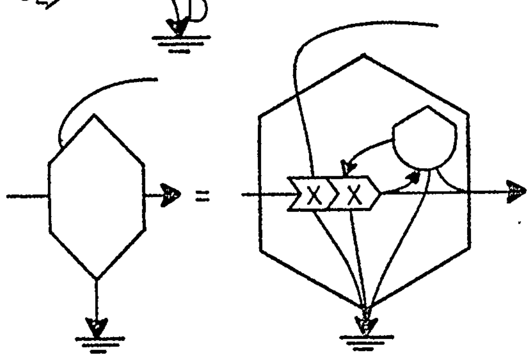
$$J = \frac{kJ_0}{1+k}$$

- Source limited external source delivers limited flow (J_o) which is tapped by flux dependent pathway (J).



$$\dot{Q} = J_1 + J_2 - J_3 - D$$

- Storage symbol for state variables drawn to resemble a tank.



- Self maintaining units with upgraded storage, autocatalytic pumping, and various related self organizing pathways are indicated with hexagon class symbol.

Odum's (1974) particular application of this technique in ecology is based on the theory that all events in the reality continuum involve some type of energy flow. As a result, certain constraints and characteristics inherent to functioning systems are generated by the laws of energy. The symbolic language used by Odum (1974) is energy circuit language so that a system's organizational relationships are represented by the process and order generated in energy flow.

The benefits of visual systems mathematics to systems analysis in systems ecology are:

- it is a non-numerical technique that contains the same information (Odum, 1974) as the equations and matrices used in quantitative modelling and analysis.
- it is applicable at a macroscopic scale.
- it represents system processes and organizational relationships rather than state conditions.
- it can be visually understood and therefore more easily used as a conceptual tool.
- the systems diagrams that result are essentially isomorphic models and consistent with the isomorphic nature of systems theory.
- the use of energy circuit language as a symbolic language is applicable to the relationship of energy flow to the organizational structure ecosystems (illustrated by the pyramid concept, trophic structure, and the entropy principle).

The use of visual systems mathematics in analysis has the potential to represent both qualitative and quantitative levels of reduction. It provides isomorphic constructs or models more easily understood as conceptually or theoretically useful tools and therefore less prone to being viewed as mathematical entities in their own right.

Developing and applying techniques for ecosystem analysis that are; concerned with functioning whole systems; consistent with qualitative and quantitative aspects of systems organization; and applicable at a macroscopic scale; are not only important in systems ecology, but have applications in the field of planning. Environmental planning must also develop similar systems analysis techniques to deal with the interactions between human economic and social systems and natural systems.

SECTION THREE:

PRACTICE

"What is the use of the ever-faster, ever-slicker, more nearly perfect implementation of rotten plans?"

- Stafford Beer

(1972)

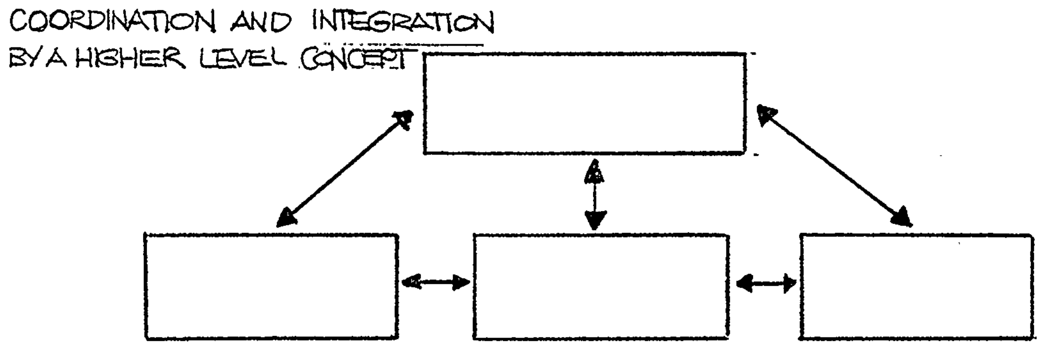
CHAPTER FIVE: THE IMPLICATIONS OF APPLYING A SYSTEMS FRAMEWORK IN ENVIRONMENTAL PLANNING

In the Introduction, environmental problems were described as interdisciplinary in nature, involving complex networks of interactions between social, political, historical, technological, economic and biophysical factors. The concept of systems described in Chapter One involves thinking in terms of integrated 'wholes' or sets of interacting, interrelated elements. Such organized sets of networks of interacting or interrelated biophysical factors are conceived of as ecological systems by analogy to the characteristics of the general system construct (discussed in Chapters Two and Three). In this sense, the systems concept can also be applied to the complex networks of relationships between social, political, economic, technological, and biophysical factors that constitute environmental problems. It will still be necessary to act upon discrete elements or subsystems but a systems approach can inprove our ability to plan without incurring unanticipated system impacts.

THE ROLE OF ENVIRONMENTAL SCIENCE

Environmental Science (as described in the project's introduction) is an interdisciplinary field concerned with understanding the interactions between human activities and the biophysical environment in order to plan and manage such interactions for the mutual benefit of both.

Interdisciplinarity, as described by Jantsch (Johnson, 1977), is the coordination or integration of information by a higher level concept. The structural or organizational relationships involved in an interdisciplinary model can be represented as follows:



In terms of environmental science, a concept that integrates information from related environmental factors is the ecosystem concept. Since the science of ecology is concerned with understanding the structure, function, and behavior of ecological system, it often assumes the higher level integrative function in environmental science. However, environmental science is concerned with the interactions or integration of human activities within ecological systems; the effects of human activity are important parameters in ecological systems. All too often, the human species as a biological population and its technology, is not considered as an ecosystem component in ecological studies (Johnson, 1977). It must be recognized that it is the systems concept that is the integrative higher order concept in interdisciplinary environmental work rather than ecology or a narrowly defined concept of ecosystem. Both human activities and biophysical factors can be conceived of as systems at some level of organizational complexity within a systems framework. The theory and conceptual framework of systems thinking must provide the integrative function in environmental science.

To this end, the planning function involved in environmental science is compatible with an interdisciplinary approach based on a systems view.

THE PLANNING PROCESS AS A CONCEPTUAL SYSTEM

Planning is defined by Jubenville (1976), as a process involving "...a deliberate attempt to focus our thinking on a specific problem or problems in order to create rational means of solving them or to achieve established common goals and objectives." Chadwick (1971) describes planning as "...a general human activity...involving a process of thought and action based on that thought-forethought, about the future."

On the basis of both definitions, planning emerges as a human problem-solving activity that involves a process of rational thought and action (based on that thought) to meet established goals and objectives for the future.

The course of action formulated by the planning process constitutes a plan. Plans are not decisions, but general outlines of the direction planning actions should take to achieve desired goals and objectives. Plans are tools or guides for decision-making that act as primary mechanisms for instituting a process of change (Jubenville, 1976).

As a human activity, the process of planning is directed towards human interactions with some aspect of the environment either the man-made environment or the natural environment. As a biological species, all human activities take place within and are ultimately dependent (in some form) on the resources of the natural environment.

The systems concept is based on organizational relationships between some selected set of interacting elements; in the case of the planning process, it is the relationships and interactions within and between human and natural environments.

The application of the systems concept to the set of interactions between the human species and the biosphere results in the construct of a man/nature system (Chadwick, 1971) that provides a broad conceptual framework for viewing human activities. Chadwick (1971) identifies 4 major components or subsystems that constitute the man/nature system:

i) the biosphere as an ecological system

ii) human value systems

iii) human activity systems

iv) human systems of adapted spaces

The whole system is a complex set of relationships involving human interactions with the biosphere in both a biological and cultural sense. These interactions involve human value systems that lead to specific kinds of activities that result in modifications to the natural environment to meet human needs. Figures 14 and 15 illustrate alternative representations of the man/nature system.

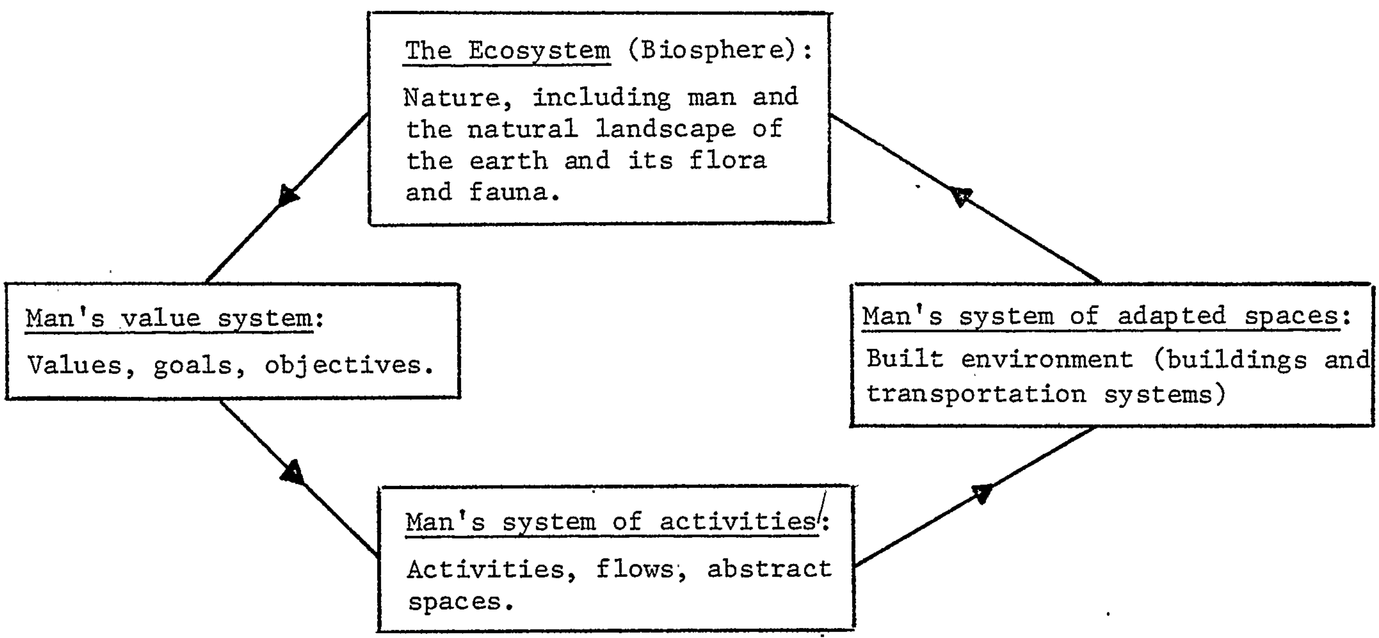


FIGURE 14
The Man/Nature System
Source: Chadwick (1971)

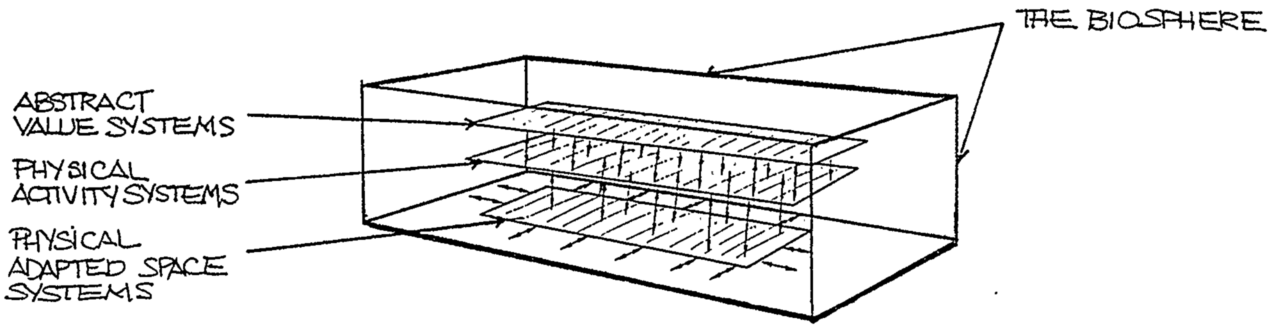


FIGURE 15
An Alternative Representation Of The Man/Nature System
Source: Chadwick (1971)

The planning process, as a human problem-solving activity based on rational thought and action, will, to some degree, involve abstract value systems, physical activity systems, adapted physical space systems, and resources of the natural environment. As a result, planning activity takes place within the framework of the man/nature system.

To deal with problems in a systems context the planning process requires systems analysis. In the same way that systems ecology involves systems analysis to create theoretical constructs or models of ecological systems; the planning process also develops models of selected relationships abstracted from the man/nature system. These planning models are then analyzed in an attempt to identify and forecast future conditions of selected relationships as a basis for evaluating alternative courses of action that will meet the desired objectives of the planning activity.

Planning models and ecological models are not 'mirrors of reality' but conceptual tools that can be used as rational constructs to gain an understanding of reality phenomena and provide a framework from which operational theories and techniques can be derived.

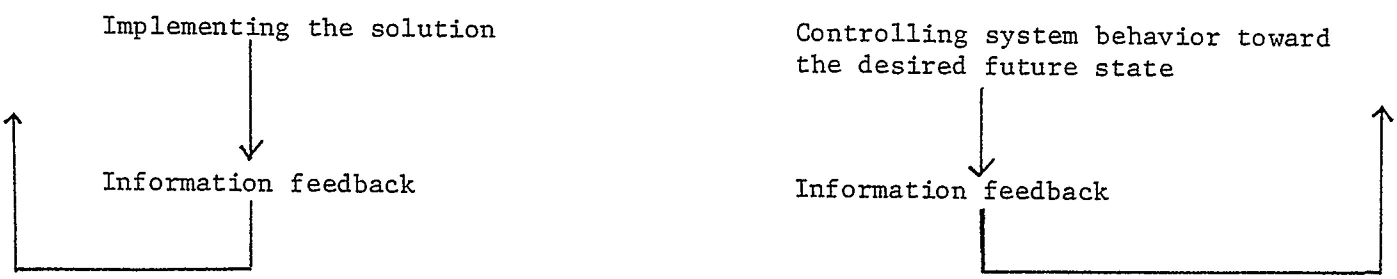
PLANNING AS A METHOD OF PROBLEM SOLVING

Planning is a general method independent of the field in which it is practiced (Chadwick, 1971).

Within a conceptual systems framework, the general method of planning involves the use of general systems theory (including information theory and cybernetics) and the scientific method.

Chadwick (1971) describes the phases of a rational general planning method (derived from systems theory and the application of the scientific method) as:

Formulation of the problem	⇄	Recognition and description of the system
↓		↓
Formulation of criteria which the problem solution must satisfy	⇄	Formulation of criteria for testing the system
↓		↓
Modelling the problem	⇄	Modelling the system
↓		↓
Testing the model against the criteria	⇄	Testing the system model against the criteria
↓		↓
Deriving a solution from the model	⇄	Projecting the alternative models of the system's future state
↓		↓
Testing the solution against the criteria	⇄	Testing the projected future state against the criteria
↓		↓



An alternative description of the common stages involved in a general method of planning (similar to Jubenville's (1976) description) might include:

- Problem identification and definition
- Identification of planning resources and constraints
- Establishment of goals and objectives to be achieved in problem-solving
- Projection of variables involved in identified problem into a future time frame to forecast future change based on present conditions
- Develop alternative courses of action and action priorities based on previous stages
- Evaluation of alternative actions based on stages 2 and 3 plus feasibility of implementation
- Coordination and implementation of selected actions
- Monitoring and evaluation of implemented actions
- Periodic revision of actions based on stage monitoring and evaluation information.

These stages are not necessarily carried out in a linear sequence. Rather, there is usually a cyclic flow of information and feedback between stages which merge them into a functioning whole process illustrated in Figure 16.

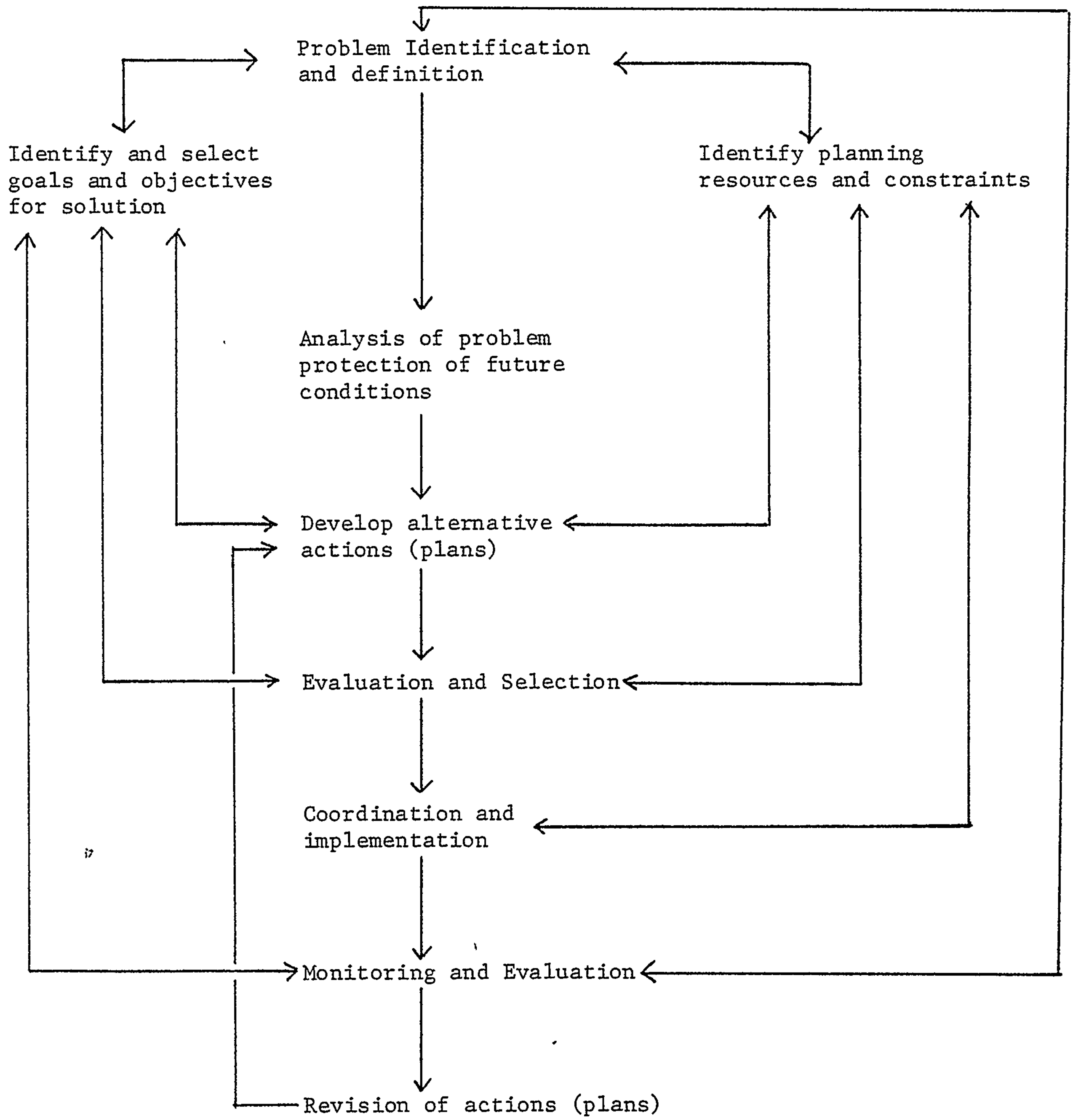


FIGURE 16
Information Flow And Feedback In The Planning Process

Planning, as a general method for problem solving, must be functional. Plans are the primary mechanisms for change resulting from the planning process. Plans are no better than their implementation, administration, or management (Jubenville, 1976). The planning process must reflect the requirements necessary for implementing and managing its courses of action. For example, Jubenville (1976) states, "...one cannot plan for one objective and manage for another".

A functional relationship between planning and management activities is important. Planning only provides directions for future action and change. These directions or plans are not in themselves decisions for the future but guides for future decision-making. The course of future action provided by the planning process will not take place in a vacuum, but in the dynamic probabilistic (unpredictable) context of reality. As a result, the implementation of a course of action requires constant decision-making and adjustment in order to achieve or re-evaluate planning objectives affected by changing circumstances.

Organizational relationships change over time and with increasing complexity. The man/nature system is a portion of the space-time continuum of reality that also undergoes organizational change with time and increasing complexity. In this system, changes are intensified by the process of demophoric growth (discussed in the introduction to Section One) involving; the combined biological and technological effects of an increasing human population and; the corresponding increase in resource consumption and production and; the principle of the 'second dilemma' (increasing complexity with increasing relationships).

As demophoric growth occurs over time, the numbers of elements within the system increase creating more possibilities of interactions between system components and thus increasing the complexity (variety) of system relationships.

Planning activities within the man/nature system framework involve interactions and relationships between selected system components. The planning process must deal with changing organizational relationships within this system that occur over time with increasing complexity. Therefore, the course of action or direction of future change resulting from the planning process involves the modification or arrangement of selected organizational relationships and/or their spatial patterns over time (Chadwick, 1971).

The planning process and its related management process must both be concerned with future organizational relationships and corresponding state conditions within the man/nature system and its component subsystems.

ENVIRONMENTAL PLANNING

Planning has just been described as a problem-solving process within the conceptual framework of the man/nature system. The planning process is a general method independent from the field or discipline in which it is practiced. This general method is consistent whether applied in town planning, regional planning, economic planning, transportation planning, or recreational planning, although specific planning techniques will vary with different problems and objectives for problem-solving.

The field of ecology has been described in Section Two as the study of interrelationships between living (biotic) organisms and their physical environment. The basic 'unit' or construct of the natural environment and the fundamental concept in ecology is the ecosystem (Dansereau, 1971; Odum, 1971; Smith, 1976). The biosphere is the macroscopic ecosystem of the earth.

It is composed of ecological subsystems which are ecosystems in their own right at a lower hierarchical level of the organizational continuum.

Ecosystems are 'open' or connected through; interactions, process, flows of information energy and matter, and input-output relationships with the biosphere, which is itself open to higher order continuum systems (the universe for example). The biosphere and its component ecological systems are the major component in the man/nature system in which all human activities take place. The human species is an integral component of the biosphere that interacts with the physical environment in both a biological and cultural sense. Abstract human value systems, human activity systems, and adapted physical space systems all exist within an ecological system context. In this general sense, all planning involves problem-solving within the environment of the human/nature system.

However, "environmental planning" will be used here to describe the application of the planning process to direct and conscious human interactions and modifications of ecological systems. The choice of the term "environmental planning" is preferable to terms with similar connotations such as land use planning and resource planning. The reason for this choice is that the ecosystem concept is inherent in environmental study, whereas the terms resource and land use planning imply a more singular or atomistic approach to a specific land use or resource. Ecological systems are functioning wholes, the components and processes of which cannot be isolated from their system context.

The primary objective of environmental planning is to integrate the structure, function and behavior of human and natural systems and apply this knowledge in problem-solving activities involving the interactions within and between these systems and their subsystems. Environmental planning deals with problems related to human interactions with landscape resources within a systems framework utilizing theories and techniques consistent with a systems approach.

For example, environmental planning for logging operations within a topographic watershed must consider more than optimum siting criteria for the specific logging activity. Developing a planned course of action must involve an understanding of the interactions and effects of logging activity in the context of the entire watershed system which will include relationships between terrestrial and aquatic ecosystems that include human activity systems (social, political, and economic) as well as biophysical systems.

The objective of environmental planning is to develop a course of action that represents the synthesis of ecological systems and human activity systems.

Unfortunately synthesis is an activity that is not encouraged by the atomistic tendencies within our society (Henderson, 1975) which fragments information and dichotomizes man and nature.

For example, the interrelated, interacting components and processes involved in the concept of an ecological system are dealt with separately by many scientific disciplines most of which have further fields of specialization within themselves. For example:

- Botany
- Geography
- Zoology
- Entomology
- Geology
- Chemistry
- Physics

- Hydrology
- Climatology
- Anthropology

Even the science of ecology, in which the concept of ecosystem is fundamental, is divided into areas of specialization; such as, plant ecology, animal ecology, aquatic ecology, synecology, autecology, and systems ecology.

The social institutions within society responsible for policy, planning, and decision-making have also become separate and fragmented, Hazel Henderson (1975) states...

"Our organizations are narrow and often single purposed whether corporations, government agencies, or committees of the Congress (House of Commons). In fact organizations are devices for screening out, impounding or distorting information, so as to better pursue their goals."

The magnitude and complexity of dealing with a functioning, interrlated whole such as the man/nature system has made dealing with its component parts appear much easier than dealing with the whole. However, the problems faced by society involve the whole system, and do not fall neatly into atomistic categories. The majority of important problems facing society arise at the interfaces of our information and organizational categories (Henderson, 1975). This is not surprising since the reality continuum is a four-dimensional space-time continuum of organizational relationships or probabilities of interconnections; and not a static two-dimensional aggregate of atomistic parts. The apparent 'overlap' between atomistic categories of knowledge emphasizes the 'integrated' nature of the reality continuum as a functioning whole system.

Planning problems arise when the problem to be solved involves several categories of information and the function of more than one social organization or institution, since overlapping information and function does not necessarily imply integration; an aggregate of information is not an information system.

For example, the current practice of multiple land use planning acknowledges the need for coordination between overlapping land use activities and the agencies or institutions responsible for these activities within a particular geographic area. However, the approach to multiple use planning has commonly been fragmented on a discipline basis (Jubenville, 1976); biologists, hydrologists, geologists, soil scientists, independently contribute information from their separate disciplines; agencies and institutions contribute information on political boundaries, land ownership, current uses, policy, zoning, setbacks and right-of-way regulations. In order to synthesize this information, mapping techniques are commonly used to visually 'overlay' this information in order to determine areas of conflict, and therefore spatially arrange land uses to minimize the identified conflicts. While this technique may smooth over the edges between overlapping information, it does not assure that the information is integrated or that the results are compatible with the structure, function and behavior of the social or the ecological systems involved. Without identifying a conceptual system framework for viewing a multi-faceted problem prior to its analysis; there is no common approach to give direction to information gathering and no context for identifying relationships between problem components necessary to integrate information. For example, Kitchen (1976) states...

"Many 'team' studies are not carried out in an integrated fashion. At best they are multi-disciplinary in that they represent the separate findings of various experts which are then correlated (post-correlation). The need in environmental research however is for pre-coorelation. The various participants must have a clear understanding of the purposes of the study and the type of information that is required of them. Too often, in post-correlated studies, data has not been collected or presented in a form which can readily be adapted to the overall study objectives."

The foregoing criticism of the atomistic tendency of society to fractionate information into academic disciplines and separate the functions of its institutions and organizations is not meant to suggest that this approach is useless or that the existing structure should, or could, be done away with. Rather, the purpose of this criticism is to illustrate the need for the conceptual framework and theory of the systems approach to unify and integrate atomistic categories of information and function.

It is totally unfeasible to assume that one person, one discipline, one institution, organization, or agency, could totally understand or deal both holistically and atomistically with the entire dynamics of the man/nature system and all information therein.

A 'team' approach to solving problems in the man/nature system is imperative, but the team itself must be conceived of as a system and not an aggregate of expertise. The team as a system, must in turn develop a systems context for viewing the multi-faceted problems to be solved, and become integrated within this context so that its functions are consistent with the systems nature of the problems to be solved.

The systems approach to team problem-solving whether in research or planning can provide an integrated and complimentary alternative to the exclusive use of either a holistic or atomistic approach (discussed in Section One). Environmental planning must use the systems approach in order to:

- provide the "pre-correlation" (Kitchen, 1976) or integrated context required for the synthesis of information and functions involved in the interactions between human activity systems and ecological systems.

- integrate the theory and techniques of a systematic planning process with the theory and techniques of systems ecology.
- develop and utilize a common paradigm.

The Role of Systems Ecology

The effective integration of future human activity systems with functioning ecological systems requires an understanding of ecosystem dynamics; particularly the influence of human activities within ecological systems.

Ideally, systems ecology and its goals of modelling and analysis can provide an understanding of functioning whole ecosystems. However, all too frequently (Johnson, 1977) the influence of human activities on the processes, relationships, and functions of ecosystems is viewed as an externality and not included in modelling and analysis.

The major difficulties that have contributed to the omission of human activity as an integrated component of ecosystem models are:

- the scale of human interaction within the biosphere.
- the difficulty in quantifying human activities and their effects.
- the influence of the Cartesian division in the tradition of scientific thinking that encourages a view of humanity as distinct from natural phenomena.
- information concerning human activities falls into established disciplines outside the field of systems ecology.
- the constraints, in terms of time, money, and expertise, required to 'build' even simple (low variety) quantitative models of ecological systesm.

These difficulties are compounded by the problems of a predominant quantitative approach to modelling (identified in Chapter Four) summarized below;

- inclusion into the model of only those system features that can be quantified.
- the exclusion of external influences and exogenous variables.
- atomistic analysis of components or levels of organization below that of the whole system.
- mechanistic modelling techniques that assume cause and effect relationships between system states.

Planning is a human activity, and environmental planning involves interactions within human/nature systems. Environmental planning must integrate future human influences and effects on ecosystem dynamics in order to avoid the deterioration of natural systems upon which the human species ultimately depends. The role of systems ecology in environmental planning therefore is to provide an understanding of dynamic ecosystem function through systems analysis that includes the influence and effects of human activities being planned. This role cannot be fulfilled if systems ecology in its present quantitative model building state (with its problems of analysis and difficulties in dealing with human activity systems and influences in modelling) is incorporated into the planning process.

Systems analysis, like the planning process, is a general method independent of the field in which it is applied. The process of systems analysis involves:

- selecting and describing a system construct
- modelling the selected system construct
- projecting and testing the model

A model is a symbolic representation of a set of relationships. The level of explanation required, desired, or possible, influences the type of model selected to represent the relationships being examined. As discussed in Chapters Two and Four, homomorphic (heuristic) and isomorphic (phenomenological) models are non-numerical representations of relationships that serve as logical prior steps to a quantitative analytical level of reduction. The emphasis of the systems approach is on relationships between an interacting set of elements, so that the precise physical and/or biological properties of a set of elements is secondary, and can be treated as 'black boxes'. In this sense, systems theory is a body of isomorphic constructs concerned only with organizational relationships and common organizational features at a phenomenological level of explanation. Developing non-numerical isomorphic models in systems analysis is a valid application of the systems approach and can serve as a valuable prior step to quantification in developing numerical analytical models.

The use of systems analysis in systems ecology does not implicitly imply the use of quantitative techniques and the development of numerical analytic models. Odum's use of visual systems mathematics, as an example of a non-numerical technique in modelling (discussed in Chapter Four), is a case in point.

The present use of quantitative techniques for analytical modelling cannot deal with the relationships and processes of human activity systems and ecological systems at the scale required for planning, therefore the conscious use and development of isomorphic models involving non-numerical techniques for a macrosystem approach to systems analysis should be considered in systems ecology for environmental planning. Otherwise, the difficulties and analysis problems (described in Chapter Four) associated with current modelling and analysis techniques in systems ecology will continue to present very real difficulties to environmental planning.

The use of isomorphic models and non-numerical techniques of analysis in systems ecology is a valid application of the systems approach, consistent with an environmental planning framework. It is not, however, a popular approach in Western scientific thinking where quantitative traditions and atomistic analysis inherited from Newtonian physics are still strong, and causal explanation and analytical mathematical models are equated with "good" science. As Chadwick (1971) states...

"It is important not to equate 'intuitive' with 'poor' or 'partial', and 'rational' mathematical models with 'good'. The planning process is in great need of human qualities, both rational powers of argument and descriptive abilities."

THE IMPORTANCE OF A SYSTEMS PARADIGM IN ENVIRONMENTAL SCIENCE

A paradigm represents a theoretical structure or pattern that provides the conceptual and contextual status that characterizes the approach of a scientific field to its area of study at a particular time (Chadwick, 1971; Johnson, 1977). An important function of a paradigm, in addition to that just described, is to clarify the assumptions involved in the approach being taken by a particular scientific field.

Without a common paradigm for an integrated interdisciplinary approach, the social and scientific fields of study involved in environmental problem-solving may find that the assumptions involved in their individual approaches to an interdisciplinary problem area may be inappropriate to the nature of the problem. Johnson (1977) provides an example of "...technological answers to congested highways, low income housing, and other complex social dilemmas that often fail because they are defined narrowly as engineering problems without reference to the cultural context in which their solutions must thrive..."

If the underlying paradigm of a scientific discipline is incompatible with the nature of the problem area being addressed, then the application of a scientific discipline may be counterproductive to solving the problem. In the case of environmental science, environmental problem-solving involves dealing with the structure, function, and behavior of complex probabilistic systems, both human and biophysical. It cannot approach such problems with a traditional paradigm that assumes simple cause-and-effect and ignores systematic relationships.

A systems framework provides not only a higher order concept for integration within the interdisciplinary approach of environmental science, it also provides a conceptual framework for evaluating the characteristic features and assumptions associated with a particular paradigm.

To this end, the "mutual causal paradigm" proposed by Oakridge University Associates (Johnson, 1977) places emphasis on; networks of interrelationships, contextual relationships, information flow, complexity, interpretation, feedback, and participatory planning. All of these features are consistent with the nature of systems thinking presented throughout this project. The description of the mutual causal paradigm follows in Figure 17.

Applying a systems framework, and developing associated paradigms, for application to interdisciplinary environmental problem-solving activities is a difficult process because these problems occur at the interfaces of existing atomistic disciplines and social institutions. As a result, any attempt at dealing with problems at these interfaces must address formidable gaps of knowledge, semantic, and methodological barriers, because of the atomistic nature of Western science and governmental structure. For example, di Castri (1976) identifies the lack of integration which currently exists between:

	UNIDIRECTIONAL CAUSAL PARADIGM	RANDOM PROCESS PARADIGM	MUTUAL CAUSAL PARADIGM
Social organization:	hierachical	individualistic	non-hierarchical interactionist
Ethics:	competitive	isolationist	symbiotic
Philosophy:	universalism	nominalism	network
Perception:	categorical	atomistic	contextual
Logic:	deductive, axiomatic	inductive, empirical	complementary
Science:	traditional "cause" and "effect" model	thermodynamics; Shannon's information theory	post-Shannon information theory
Research hypothesis and research strategy:	dissimilar results have been caused by dissimilar conditions. Trace to conditions producing them.	there is probability distribution; find out probability distribution	dissimilar results may come from similar conditions due to mutually amplifying network. Network analysis instead of tracing of the difference back to initial conditions
Methodology:	classificational, taxonomic	statistical	relational, contextual analysis, network analysis
Information:	past and future inferrable form	information decays and gets lost; blueprint must contain more information than finished product.	information can be generated. Nonredundant complexity can be generated without preestablished blueprint.
Knowledge:	believe in one truth. If people are informed, they will agree.	why bother to learn beyond one's interest	Polyocular: must learn different views and take them into consideration.
Analysis:	pre-set categories used for all situations	limited categories for his own use	changeable categories depending on situation
Assessment:	"impact" analysis	what does it do to me?	look for feedback loops for self-cancellation or self-reinforcement
Decision process:	agency dictated	entrepreneur	participatory planning and evaluation
Esthetics:	unity by similarity and repetition	haphazard	harmony of diversity

FIGURE 17

Description And Comparison Of The Mutual Causal Paradigm

Source: Johnson (1977)

- disciplines within the natural sciences
- disciplines within the social sciences
- the natural and social sciences
- research and decision-making processes
- academic and governmental structures

The atomistic tendency which leads to the lack of integration in di Castri's (1976) examples, is primarily the result of the indefinitely large complex nature of the human/nature system in which human activity systems operate. It is much easier to divide problems into small atomistic components which can be more easily conceived of than to attempt to conceive of the complex interrelationships involved in the human/nature system. This atomistic approach permeates our institutional and idealogical structures and is perpetuated by the educational functions of these structures. Breaking out of this cycle is necessary if we are to deal effectively with the environmental problems which occur at the interfaces of atomistic knowledge and social organization. To this end, the application of systems theory in environmental science and the acceptance of an associated paradigm can assist in applying a systems framework or conceptual 'map' to the complex networks of social and biophysical interactions involved in environmental problems.

Graham-Smith (1978) states...

"We live in a world of interacting systems, and their organizations of different types, each with a different nature and involving different kinds of problems. It follows that if we are to understand our world, ourselves, and our place in it, and develop these constructively, we need to think in terms of organization and its transformations. We are, in principle, quite capable of doing this. Rather strangely however, this all-pervading role of organization was first appreciated only some thirty years ago, and it is still not widely integrated into the pattern of our thought."

CONCLUSIONS

On the basis of the information presented in this project, major conclusions relevant to the successful application of the systems framework in environmental planning are formally identified below:

i) A systems approach is necessary if we are to understand and work with systems. Such an approach is complementary to both holistic and atomistic approaches in that it provides a synthesis function for integrating organizational relationships of differing levels of complexity. Conclusions or information from system components resulting from an atomistic approach may in fact be correct but this approach falls short of understanding the system as a whole; the behavior of a functioning whole system is not the same as the sum of its component parts since these components are less complex levels of organization than the system itself. It is our inability to understand and deal with the macrosystem level of organization and complexity rather than the need for ever more detailed atomistic analysis that leads to problems in dealing with indefinitely large or indefinitely small unpredictable phenomena.

ii) A systems approach is complementary to existing atomistic approaches in ecosystem analysis. If the objective of ecosystem analysis is to develop analytic models at a causal level of explanation, a systems approach can provide the heuristic and phenomenological levels of explanation that are the logical and necessary prior steps to a causal level of reduction.

iii) System models are abstractions of reality and not reality itself. As such, models must serve as conceptual or theoretical tools in developing better approximations of our perceived reality and techniques for evaluating our perceptions.

iv) The use of quantitative techniques in developing analytic models must not omit or overlook; the importance of system properties that may not be measurable or quantifiable or; the fact that Newtonian laws and mechanics may not be appropriate for describing certain system features such as system motion in complex, indefinitely large systems. Too often, the conceptual and theoretical importance of understanding relationships at and between levels of organization that constitute a system construct are overlooked in favour of discrete quantitative bits of data.

v) The interdisciplinary nature of environmental problems requires the development of common paradigms and problem solving techniques that utilize the conceptual and theoretical tools provided by a systems approach. An interdisciplinary team approach is a synthesis, not an aggregation of expertise.

vi) The development of a common or standardized vocabulary for systems descriptors or terminology is a necessary step in the development of a unified and consistent reference for interdisciplinary work and the development of a common interdisciplinary paradigm for environmental problem solving.

REFERENCES

Beer, Stafford. 1959. Cybernetics and Management. English Universities Press.

Beer, Stafford. 1972. Brain of the Firm: The Managerial Cybernetics of Organization. Allen Lane the Penguin Press.

Boulding, Kenneth E. 1956. "General Systems Theory: the Skeleton of the Science", Management Science, Vol. 2, pp. 197-208.

Capra, Fritjof. 1975. The Tao of Physics, 2nd edition. Fontana Books (The Chaucer Press, 1976).

Chadwick, George. 1971. A Systems View of Planning, 3rd edition. Pergamon Press Ltd.

Clay, Grady. 1963. "Editorial", Journal of Landscape Architecture, Vol. 53.

Collier, Boyd D; Cox, George W; Johnson, Albert W; Miller, Philip C. 1973. Dynamic Ecology. Prentice-Hall Inc, Englewood Cliffs, N.J.

Dansereau, Pierre. 1971. "Dimensions of Environmental Quality", Sarracenia, No. 14, p. 109.

Dale, M. B. 1970. "Systems Analysis and Ecology", Ecology, Vol. 51, No. 1, pp. 2-16.

Darling, F. Fraser. 1966. "Introduction", Future Environments of North America. F. Fraser Darling and John P. Milton (eds). The Natural History Press, Garden City, New York.

Diamond, Philip. 1974. "Models Describing Energy Flow and Nutrient Cycles in Ecosystems", Unifying Concepts in Ecology. Junk Publishers. The Hague.

di Castri, Francesco. 1976. "International, Interdisciplinary Research in Ecology: Some Problems of Organization and Execution", Human Ecology, Vol. 4, No. 3, p. 235.

Eiseley, Lorne. 1961. Darwins Century. Anchor Books, Doubleday and Company, Inc. Garden City, New York.

Fiebleman, J. K. 1954. "The Theory of Integrative Levels", British Journal for the Philosophy of Science, Vol. 5, pp. 59-66.

Gorden, Morton and Gorden, Marsha. 1972. Environmental Management: Science and Politics. Allyn and Bacon Inc. Boston.

Graham-Smith, W. 1978. "Organization in Natural Systems", Ecologist Quarterly, Summer 1978, p. 114.

Heisenberg, W. 1963. Physics and Philosophy. Allen and Unwin. London.

Holling, C. S. 1973. "Resilience and Stability in Ecological Systems", Ann. Review of Ecology and Systematics, Vol. 4, pp. 1-23.

Holling, C. S. and Goldberg, M. A. 1971. "Ecology and Planning", American Institute of Planners Journal, July, 1971, pp. 221-230.

Iberall, Arthur S. 1972. Toward a General Science of Viable Systems. McGraw-Hill Book Company.

Innis, G. 1974. "Stability, Sensitivity, Resilience, Persistence: What is of Interest?", Ecosystem Analysis and Prediction. Proceedings of the SIAM-SIMS Conference, July 1974. Alta, Utah.

Isard, Walter. 1972. Ecologic-Economic Analysis for Regional Development. The Free Press, New York.

Johnson, Philip L. (ed). 1977. An Ecosystem Paradigm For Ecology. Oak Ridge Associated Universities.

Jubenville, Alan. 1976. Outdoor Recreation Planning. W. B. Saunders Company, Philadelphia.

Kerr, S. R. 1974. "Structural Analysis of Aquatic Communities", Unifying Concepts in Ecology. Junk Publishers, The Hague.

Kitchen, Cameron M. 1976. "Ecology and Urban Development: The Theory and Practice of Ecoplanning in Canada", Canada's Natural Environment. McBoyle, G. R. and Sommerville, E. (eds). Methuen Publications, Toronto.

Klir, J. and Valach, M. 1967. Cybernetic Modelling. Iliffe Books Ltd.

Laszlo, Ervin. 1972. The Systems View of the World; the Natural Philosophy of the New Developments in the Sciences. G. Braziller. New York.

Levin, Simona. 1974. "Disturbance, Patch Formation, and Community Structure", Proc. Natl. Acad. Sci. U.S.A, Vol. 71, No. 7, pp. 2744-2747.

Lindeman, R. L. 1942. "The Trophic Dynamic Aspect of Ecology", Ecology, Vol. 23, pp. 399-418.

Major, Jack. 1969. "Historical Development of the Ecosystem Concept", The Ecosystem Concept in Natural Resource Management. Van Dyne, G. (ed). Academic Press. p. 9.

Margenau, Henry. 1950. The Nature of Physical Reality: A Philosophy of Modern Physics. McGraw-Hill Book Co.

McHarg, Ian. 1969. Design with Nature. Natural History Press. Garden City. New York.

McHarg, Ian. 1977. "Champion for Design with Nature", Science, Vol. 195, No. 4276, p. 381.

Moore, Patrick, 1966. Principles of Statistical Techniques, 2nd edition. Cambridge University Press, London.

Morales, R. 1974. "A Philosophical Approach to Mathematical Approaches to Ecology", Ecosystem Analysis and Prediction. Proceedings of the SIAM-SIMS Conference, July, 1974. Alta, Utah.

Odum, Eugene P.. 1971. Fundamentals of Ecology, 3rd edition. W. B. Saunders Co. Philadelphia.

Odum, Howard T. 1974. "Combining Energy Laws and Corollaries of the Maximum Power Principle with Visual Mathematics", Ecosystem Analysis and Prediction. Proceedings of the SIAM-SIMS Conference. July, 1974. Alta, Utah.

Pirsig, Robert M. 1974. Zen and the Art of Motorcycle Maintenance, 6th edition. Bantam Books (William Morrow and Company Inc.)

Rosen, Robert. 1972. "Are the Dynamics of a System Operationally Determinable", J. of Theoretical Biology, Vol. 36. pp. 635-638.

Shultz, Arnold M. 1969. "A Study of an Ecosystem: The Arctic Tundra", The Ecosystem Concept in Natural Resource Management. Van Dyne, G. (ed). Academic Press. p. 77.

Slobodkin, L. B. 1974. "Comments from a Biologist to a Mathematician", Ecosystem Analysis and Prediction. Proceedings of the SIAM-SIMS Conference, July, 1974. Alta, Utah.

Smith, Robert Leo. 1976. "Concept of the Ecosystem", The Ecology of Man: An Ecosystem Approach, 2nd edition. Harper and Row Publishers.

University of Alberta Population Research Laboratory, Dept. of Sociology. 1977. Proceedings of the Social Indicators Conference. May, 1975, Edmonton, Canada.

Van Dyne, George. 1969. "Implementing the Ecosystem Concept in Training in the Natural Resource Sciences", The Ecosystem Concept in Natural Resource Management. Van Dyne, G. (ed). Academic Press, p. 328.

Vincent, T. L; Pulliam, R. H; Everett, L. G. 1974. "Modeling and Management of Ecosystems Via Optimal Control Theory", Unifying Concepts in Ecology. Junk Publishers, The Hague.

Von Bertalanffy, Ludwig. 1950. "The Theory of Open Systems in Physics and Biology", Science, Vol. III, pp. 23-29.

Wetzel, Robert G. 1975. Limnology. W. B. Saunders Company. Philadelphia.

Whitehead, Alfred North. 1925. An Enquiry concerning the Principles of Natural Knowledge, 2nd edition. Cambridge University Press.

Woodwell, G. M. 1970. "Effects of Pollution on the Structure and Physiology of Ecosystems", Science, Vol. 168, April. p. 429.