This is to certify that the

thesis entitled

A CONCEPTUAL FRAMEWORK FOR
ECOSYSTEM PLANNING AND MANAGEMENT

presented by

Michael Robert Thomas

has been accepted towards fulfillment
of the requirements for

Doctor of Philosophy degree in Resource Development

Ronald L. Shelton
Major professor

Date 22 July 1980

A CONCEPTUAL FRAMEWORK FOR ECOSYSTEM PLANNING AND MANAGEMENT

By

Michael Robert Thomas

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Resource Development

1980

ABSTRACT

A CONCEPTUAL FRAMEWORK FOR
ECOSYSTEM PLANNING AND MANAGEMENT

By

Michael Robert Thomas

Most of the earth's ecosystems have been significantly altered by human activities - either by direct and indirect exploitation of natural resources or by waste products of industrial, agricultural, or domestic processes. In addition, an increasing world population will require more extensive and intensive use of ecological systems to satisfy its future needs. There is concern that continued and uncontrolled development of natural ecosystems will result in irreversible damage to those systems and their dependent life forms and, ultimately, human systems.

A holistic and systematic ecosystems approach to land use planning and management is advocated to direct the renewal and maintenance of natural and human ecosystems, thus ensuring long-term availability of resources and quality living environments. The ecosystem concept is fundamental to this process. An ecosystem is the geographical location where living organisms interact with each other and with their nonliving environment. The impacts of any human modification or manipulation on various ecosystem components can be studied, quantified, or monitored at the ecosystem level. Thus, the ecosystem concept becomes a working principle with tremendous potential for addressing environmental

problems, planning the renewal and maintenance of essential ecosystems, and providing a basis for responsible and intelligent interactions between humans and their environment.

Decisions on the use of ecosystems - particularly land and land resources - are influenced by a variety of factors depending on identified or perceived needs of human systems or institutions. Differences in the expertise, philosophies, and problem-solving approaches of decision makers representing the interests of social, political, legal, economic, and technological institutions require a planning and management framework which provides a common communications base and organizing structure. A review of state-of-the-art literature in environmental planning, resource management, systems science, and ecological theory reveals that an ecologically sound land use planning and management methodology can be developed to serve this purpose.

Such an ecologically sound planning and management methodology is an organization of information, both factual and theoretical, provided by the various disciplines; a careful simulation and testing of ideas and strategies for resource development and use; and an advocacy of environmental quality. Ecological theory provides the conceptual framework which ties this methodology together.

Chapters Two through Four have been organized to provide a conceptual framework describing the value of ecological theory in planning land uses. The value of this is threefold. First, ecological theory provides a systematic organization of the complex interconnections and interdependencies found within living ecosystems. Orienting information within a systems structure will assist decision makers in solving problems through an understanding of ecosystem structures and functions.

Secondly, a study of ecology provides a focus for planning and management that is based on ecological principles or constraints. This focus can lead to planning strategies (further described in Chapter Five) that efficiently collect and utilize information to adequately assess environmental constraints, opportunities, and impacts. Finally, ecological theory can provide the understanding that humans are integral parts of ecosystems and, thus, are bound by the same laws that govern all natural ecosystems despite the increasing ability and opportunity to modify nature. Chapter Six shows that management programs can be established which are closely attuned to ecological principles and philosophies of long-term, constructive interactions between human and natural systems.

ACKNOWLEDGMENTS

I would like to take this opportunity to express my appreciation for the assistance, helpful criticism, and advice given to me by the members of my guidance committee, Dr. Ronald L. Shelton, Dr. Clifford R. Humphrys, Dr. Sanford S. Farness, and Dr. Harold A. Winters. Their dedication and professionalism helped instill in me the desire to see this project through. Dr. Ronald L. Shelton, my major professor, deserves special thanks for taking the time out of his varied and busy schedule to lend extra and much-needed help in the organization and execution of my research efforts and their written results.

I would also like to thank the professional staff of the Department of Resource Development. Ms. Janine Jurcak assisted in the typing of the first draft and Mr. J. Paul Schneider helped with the graphics.

Thanks also must go to those unsung heroes in any graduate school experience - one's fellow graduate students. The numerous academic and social interactions allowed an exchange of thoughts and ideas which could only help a research effort. Valuable assistance and friendship were given by Gary P. Friday, Phillip B. Davis, and Linda S. Wennerburg, to name only a few. Happily, most of these colleagues have gone on to their deserved reward (a job) and will lend their special qualities in those environments.

My wife Rosemary deserves a special note of thanks for her love, understanding and, especially, patience during my academic career. Her contribution does not end there, however, as she edited, typed, and helped greatly in organizing this manuscript. For that, and for many other things, she has my very fond and proud gratitude.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Problem Statement

It is an obvious fact that the human populations of the United States and the world are continuing to increase. With such increases there will be a growing demand for more extensive and intensive uses of land and land resources. While it is assumed that more land will be brought into food, mineral, and fiber production to meet society's needs, there is also concern that the ecological systems that must be managed and manipulated to meet human requirements may not be able to continue functioning under the increased stresses of waste assimilation, removal of biomass, soil and mineral depletion, or uncontrolled urbanization.

During the 1960s and early 1970s, warnings of impending ecological disaster began to be heeded, and political, social, and environmental activists pressed for changes in policies and in planning and management activities which were concerned with land use. The Congress of the United States passed laws requiring cleaner air and water, protecting wilderness and scenic rivers and, ultimately, a National Environmental Policy Act (NEPA; PL 91-190 of 1969). On a global scale, the United Nations established guiding principles for the preservation and enhancement of the human environment (United Nations General Assembly, 1972).

The passage of NEPA was important in that, for the first time, a national policy was set forth whose purposes were to (1) encourage a productive and enjoyable harmony between humans and their environment by (2) stimulating health and welfare while preventing or eliminating environmental damage and to (3) enrich the understanding of the ecological systems and natural resources important to the nation (NEPA, op. cit.). In Section 102C, NEPA required that federally funded projects had to submit environmental impact statements (EIS) for the public record. The EIS contained a description of the proposed activity or program and its possible alternatives, an assessment of probable impacts on the environment, and a warning of possible environmental damages before they occurred. Many states followed suit with passage of similar legislation concerning state-owned land or large municipal projects.

In the decade since the passage of NEPA, there have been hundreds of major EISs submitted on a wide range of subjects. Unfortunately, decisions concerning the environment were not always made with the three major purposes of NEPA in mind. While many impact statements were drafted that enhanced the welfare of society and prevented environmental damage, a study of the documents reveals that a majority of them do little to enrich our knowledge of ecosystems and the natural resources provided by ecosystems on which human systems depend. In addition, impact statements were criticized as obstructing progress and leading to unemployment because they did not adequately examine as many alternatives as possible and, thus, tended to be economically oriented. The EIS was rarely a document which contained adequate descriptions and evaluations of ecological systems affected by the project; basically, ecological parameters were presented as exhaustive lists and inventories of organisms present within the affected area (Davis, 1979). This pointed to a problem with environmental analysis and impact assessment methodologies which has been addressed by authors who are seeking to promote a more accurate and meaningful process in dealing with the environment.

Authors such as Odum (1975), Holling and Clark (1975), Hopkins, et. al. (1973), Andrews (1978), and others have argued that, due to its deficiencies, the EIS methodology should either be modified to reflect more ecologically oriented principles or relegated to the status of just one of many decision-making tools in environmental planning and management processes. They advocate a reevaluation of the planning and management methodologies to alter the way humans perceive and interact with their environment. Ecological constraints and principles should be placed co-equally with economic, political, technological, and social requirements in the decision-making process. This reorientation of priorities is logical in that without healthy, positively functioning ecosystems, the dependent cultural ecosystems and human institutions would ultimately fail.

Because the environment is composed of complex systems working and existing together, study in environmental areas is multidisciplinary. Each discipline, whether based on natural science, social science, or systems science, has different interpretations of its area of interest pertaining to the environment. In order for ecosystems to provide long-term benefit to both natural and human populations, decisions as to the use, management, protection, or preservation of such systems must be based on an integration of information from the various disciplines. Therefore, for proper planning and management of ecosystems, there must be meaningful communication among decision makers in land use policy, economics, business, social organizations, government, industry, and ecology. There must also be active communication between decision makers and individuals affected by decisions. This communication needs a common ground on which questions, methods, or ideas can be placed in the perspective of the solutions being sought.

In terms of natural resource management, pollution control, waste disposal, wildlife and vegetation management, urban planning, environmental engineering, recreation, and so on, the ecosystems concept can provide the focus for integration of information; communication among decision makers, planners, and managers; and coordination of human activities in the environment. The ecosystem, with its systematic interconnections of components (both living and nonliving) and processes, is the logical physical unit on the earth's surface within which management activities can be implemented and analyzed with respect to their impacts on living and nonliving subsystems.

Study Objectives

The primary objective of this research effort is to develop a conceptual framework which can provide the foundation for an ecologically based land use planning and management methodology. The ecosystem approach to the management of natural resources has been presented by Odum (1959), Watt (1968), and Van Dyne (1969) on the argument that ecological management of living systems (including humans) demands a comprehensive understanding of the ecological constraints which guide those living systems. Harris and Williams (1975) and Holling and Clark (op. cit.) call for the formulation of an ecologically based conceptual framework which will provide researchers, systems analysts, planners, and policy makers with a basic understanding of ecology and of the ecological principles which must be considered when gathering information to plan and manage ecosystems. It is an important planning goal to strive for a system which functions as naturally as possible since natural ecosystems (not merely rural ecosystems) fulfill the basic conditions for human life and are ecologically balanced (Glikson, 1971).

To achieve the primary objective, five secondary objectives were established, and these subsequently became the five major subdivisions or chapters of the study. These objectives are as follows:

(1) To provide an understanding of fundamental ecological theory along with definitions of ecosystem components and functions which are systematically interconnected in living ecosystems. A systems approach in presenting fundamental concepts provides the most direct means of translating ecological theory for decision makers with backgrounds in social, systems, and natural sciences. The chapter also introduces several conceptual models which illustrate ecosystem components and how they relate to each other.

(2) To describe the complex ecological principles by which all ecosystems, whether they are natural or human-influenced, are governed. An understanding of such principles as carrying capacity, diversity, stability (homeostasis), and resilience is necessary in providing decision makers with measures of the overall health of an ecosystem and to allow projection of what the system may do under various impacts. Several models of ecological processes are constructed and described. They

culminated in the development of a general model of an ecosystem which serves to (a) provide a basic review of ecosystems and subsystems and their interconnections and (b) allow ecosystem managers to project impacts according to their influence on the ecosystem components or processes affected.

(3) To reestablish the concept that humans and their systems are integral with the processes and functions of natural systems. This concept is necessary in redirecting the planning and management of ecosystems which have been transformed from more natural states by past uses and abuses. The decision makers must temper the desires and needs of their constituents within the perspective of ecological constraints to ensure long-term benefits to both natural and cultural ecosystems.

(4) To develop a planning strategy which efficiently gathers and integrates the most useful information in classifying, inventorying, and analyzing the environment to provide the planner with an identification of ecological constraints, opportunities, and impacts of planning efforts. The major planning objective is to develop a strategy which is flexible enough to adapt to changes in policies or in ecosystems.

(5) To develop a management program which is cognizant of ecological principles and based on a philosophy of (a) providing a decision-making path least environmentally destructive to nature, humans, and their interactions and (b) integrating human processes as parts of evolving nature as opposed to intrusions upon it.

Past Work

A review of the literature reveals that there have been few comprehensive attempts to establish an ecosystem planning and management methodology. With the exception of C. S. Hollings' Adaptive Environmental Assessment and Management (1978), which is an innovative approach to ecologically based planning and management, environmental literature is just beginning to depart from the familiar formats of prediction of doom and gloom with few practical solutions and so-called "cookbook" approaches for conducting environmental impact statements. There is a clear and present need for research efforts which can organize and integrate the information necessary to adequately describe ecosystems, their components, their functions, and their important interactions. It is also necessary to provide a decision-making tool which will allow constructive communications and interactions among decision makers.

There is a considerable number of studies which had to be analyzed for this conceptual research study. These included classical studies in ecology, methodologies for conducting environmental impact assessments, texts on the human use of ecosystems, and pioneer efforts by physical and environmental planners and managers in developing ecologically based methodologies.

CHAPTER TWO

ECOSYSTEM FUNDAMENTALS

Introduction

The study of ecosystems, their forms and functions, has been approached in a number of ways. These approaches have included the general disciplines of natural science, systems science, and resource management, with each area of study further subdivided into more specialized fields. Such study has led to a greater understanding of discrete parts of ecosystems under the general heading of "ecology" (the study of the relationships of living organisms with their environment). The initial purpose of ecological study is to conceptually and systematically place the parts into a proper and understandable whole. Ecological systems or ecosystems are the "wholes" which we seek to understand and, ultimately, manipulate for human purposes. Any human activity is therefore the result of some form of ecosystem management or manipulation.

The study of ecology was formalized only a little over a century ago, yet there have been many titles and definitions of ecosystems. According to Odum (1971), the term "ecosystem" was first proposed by Tansley in 1935 while the terms "microcosm" (Forbes, 1887), "holocoen" (Friederichs, 1930), "biosystem" (Thienemann, 1939), and "bioinert body" (Vernadsky, 1944) have also been used. Tyler (1975) has defined an ecosystem (or ecological system) as an open system with respect to material and energy flow, comprised of abiotic and biotic components in a geographical locale, whose interrelationships are such as to form a dynamic, self-perpetuating complex. He goes on to say that all ecosystems are bounded by and have interfaces with other ecosystems; each has inputs from and outputs to other ecosystems.

It is difficult for one not familiar with the sum total of everything written about ecology to understand the overall scheme of things. It often becomes necessary to stand back and view the concept of an ecosystem as a whole in order to understand exactly what is being studied. Since the study of ecology first began, various methodologies have been advocated and widely practiced in the description, study, and manipulation of ecosystems. As with any discipline which can be approached from various angles, each methodology has its advantages and shortcomings. Each contributes its unique viewpoints and discoveries which further the knowledge of a subject. On the other hand, researchers and teachers have tended to view their areas of expertise as all-important and fail to adequately communicate and integrate their knowledge to others where it could be most helpful.

The natural science approach to ecosystem study is based primarily upon the scientific method of observation, experimentation, and hypothesis formulation and testing. The majority of what is known about ecosystems comes from this approach. However, much of the "natural science" or "field" observation is being replaced by "laboratory" research in which many new facts are being uncovered. Investigators are not always able or willing to transcribe their findings into lay language or into projections of value to human systems. Many natural science texts present each ecological concept separately. A lack of communication between ecologists and the public has led to both a criticism of popularized ecological journalism as being unscientific and a failure of large portions of the public to take ecologists seriously. As a result, the fundamental ecosystem is rarely utilized as a unifying concept.

Systems scientists have recently begun to formulate ecosystem models written in computer language for the express purpose of quantifying and systematizing simple ecosystem interrelationships. The value of computer models of ecosystems has been demonstrated in organizing, summarizing and presenting a large amount of information about specific ecological factors gathered through observation, experimentation and research (Patten, 1972). On the other hand, the vast amounts of information generated by complex ecosystem models have led to overconfidence in and, sometimes, misinterpretation of the results; the quality of the results is obviously dependent on the validity of the inputs. Also, computer models are costly in terms of money and information. Simple ecosystem models may be relatively inexpensive but they lack the sophistication necessary to accurately predict ecosystem responses. Proponents of the systems approach to ecosystem study point out that, as the competence of research increases, so will the accuracy and validity of ecosystem modeling (Rapoport, 1972; Rosen, 1972).

From a strictly scientific standpoint, it is relatively simple to quantify and judge the importance of ecological fundamentals, but the significance of such fundamentals to human systems is difficult to comprehend. Therefore, the most specific methodology in need of assistance from both systems and natural science is ecosystem planning and management. For millenia, humans have been modifying, changing and, often, destroying natural ecosystems for their own benefit. For the most part, those doing the "management" were least qualified to do so. In more recent times, management has taken on a new and more dynamic meaning; ecosystem managers, whether they are foresters, road builders, or directors of nature centers, have begun to seek information and guidance through a closer interaction with systems scientists and natural scientists. The inherent strengths and weaknesses of each discipline have become magnified when put into actual practice by ecosystem managers.

What is needed, therefore, is a better understanding of what ecosystems are and why they are important as a basic unit for studying natural and human environments. By taking the fundamental concepts from systems science, natural science, and management, and by rearranging these concepts into an ecosystem framework, more rational decisions can be made pertaining to the use and protection of environments.

This chapter examines basic systems theory and how it can be used in describing ecosystems. It then proceeds into a general discussion of the components of typical ecosystems from an ecological perspective. Chapter Two, therefore, is a study of ecology from a blending of systems science and natural science. Once this framework has been introduced, certain ecological principles can be analyzed and evaluated based on natural and human ecosystem perspectives. This analysis and evaluation of ecological principles is done in Chapter Three.

Systems Classification

Ludwig von Bertalanffy is recognized as one of the pioneers in developing systems theory for biological study (Kramer and de Smit, 1977). His argument is that investigation of single parts and processes cannot provide a total understanding or explanation of living phenomena, the coordination of their parts and processes, or the laws governing such living systems (von Bertalanffy, 1928, 1934). This statement became accepted as the foundation for general systems theory. Thus, biological organisms, ecosystems, social groups, technological devices, and other organized entities can be organized and studied according to this thought process.

The concept of systems has been utilized to accurately describe and study ecosystems using both systems science and natural science approaches. Every ecosystem, whether as large as the biosphere or as small as an ephemeral rainwater pond on a forest floor, is either (1) a complete system, or (2) made up of smaller subsystems and tends to behave as a system. It is helpful to discuss systems theory before proceeding to an understanding of living and complex ecosystems.

System Definition

A system is defined as a complex unit, aggregation, or assemblage of objects joined in a regular interaction or interdependence, subject to a common plan or serving a common purpose (von Bertalanffy, 1969; Klir, 1969, 1972; Miles, 1973; Sutton and Harmon, 1973). Most people are familiar with social, educational, governmental, and mechanical systems by how these systems function for them and by the way people function as a part of such systems. Systems are discrete only with respect to the interface between their arbitrary boundaries and the surrounding environment. No matter how large a system is in the number of its different parts or components and in the function it performs, it is important to remember that systems always behave as wholes (Laszlo, 1972).

Each system is a separate entity, and all other systems are part of the environment. For example, communication and transportation (though they have many similarities), as systems, are separate from each other. The function of communication is to convey thoughts, ideas, or other forms of social intercourse, while transportation moves people or their resources from place to place. On the other hand, if transportation and communication are combined into the larger system of social institutions, they become subsystems and contribute to the holistic functioning of the larger system.

System Types

Different types of systems have been classified based on their interactions with the environment. A system is known as an open system if activities or resources outside of the system are able to cross the system boundaries to affect the inner workings of the system. The system may then modify such inputs or stimuli to produce outputs or responses. A system whose boundary is impervious to inputs or stimuli or is otherwise not affected by what occurs in the environment is a closed system. (Such closed systems are totally dependent on the Second Law of Thermodynamics - as resources are used and degraded, the system becomes less organized and able to do work.) Both open and closed systems may be able to produce outputs or responses, but only open systems can utilize resources from the environment. Closed system outputs are the results of activities carried out by finite resources inherent to the system. Well-known examples of closed systems include fossil fuels and the earth itself (von Bertalanffy, 1956; op. cit., pp. 32, 47, 102).

Open Systems

Open systems (Figure 1) can be further subdivided into natural and artificial systems. Natural systems are made up of physical, chemical, and biological components (of which humans may or may not be a naturally occurring part), interacting and evolving together without direct human intervention (Patten, 1959; Chorley, 1964; Laszlo, op. cit.). Common examples of natural systems are forests, fields, oceans, rivers, and so on.

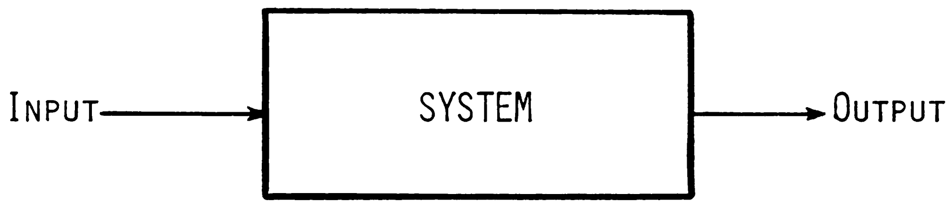

FIGURE 1. SIMPLE SYSTEM.

Artificial systems, on the other hand, have been formed by humans or human institutions to achieve a particular purpose and function. Usually, the formation of an artificial system requires the expenditure or transformation of energy and resources. Such systems are rarely compatible with the natural systems that they replace or are contemporaneous with. Artificial systems depend entirely upon natural systems for their form and function. For example, before humans developed the technology to transform basic resources into building materials such as prestressed concrete or steel, their structures reflected more closely the natural origins of the resources from which they were derived.

Architecture was limited by the ability of humans to modify logs, stone, or mud. In addition, artificial systems depend on natural systems for the energy needed for their construction and operation. Cities and other urban areas are, largely, artificial systems and would quickly perish without the constant flow of raw materials, food, and energy provided directly by natural systems or those artificial systems (e.g., agriculture) in a closer interface with natural systems.

System Structure

Von Bertalanffy (op. cit.) describes a system as a collection of parts coordinated to accomplish a set of goals. It is bounded by the environment, which provides constraints to the system. The boundary sets the system apart from its general environment, while the objective or performance of the system defines it. The components of the system accomplish the activities or goals of the system. These components may be discrete subsystems which function independently of each other, or the components may be arranged in a hierarchical series of subsystems which require some type of collective interaction to perform a function (Young, 1964). Every system has resources which are used by its components in their functions which come from within the system itself (closed system) or from the environment across the system's boundary (open system). Finally, management of the system (cybernetics) is provided by the relationships among the various components during their interactions. Such relationships may include cause and effect and feedback (Weiner, 1948; Ashby, 1956).

Studying the system as a whole tells the observer what the system does; examining the parts of a system will provide an understanding of how the system works (Laszlo, op. cit.). In all systems, the whole is usually more than the sum of its parts (Aristotelian dictum); the system (especially if it is natural) has properties no individual subsystem has. A good example of this is the telephone. Most people understand the function of a telephone and have little trouble using it. But the telephone is made up of such a complex of circuitry that it is a black box to all but electrical engineers. All the parts of the telephone must be connected and working properly in order for the telephone to operate as a communication device.

It is essential to know how subsystems and systems are interconnected in order to understand inputs and feedback which help determine system operation and stability. Feedback (Figure 2) occurs when any portion of the output is reapplied or "fed back" into the system. The state of a system is the condition or function of the system at any particular point in time, as if a photograph were taken of the system as a record (Ackoff, 1971). The system is said to be in a "set state" after output or response occurs. During feedback, part of the output reenters the system as input and modifies (either positively or negatively) the state of the system. Negative feedback is defined as that feedback which tends to maintain the stability of the system, while positive feedback usually causes the system to become unstable and self-destructive. Human population growth is an example of feedback. In primitive societies, negative feedback in the form of high birth and death rates decreases while births continue to remain constant, causing an exploding growth rate or positive feedback. Unless factors are introduced to lower the birth rate, the system may eventually self-destruct.

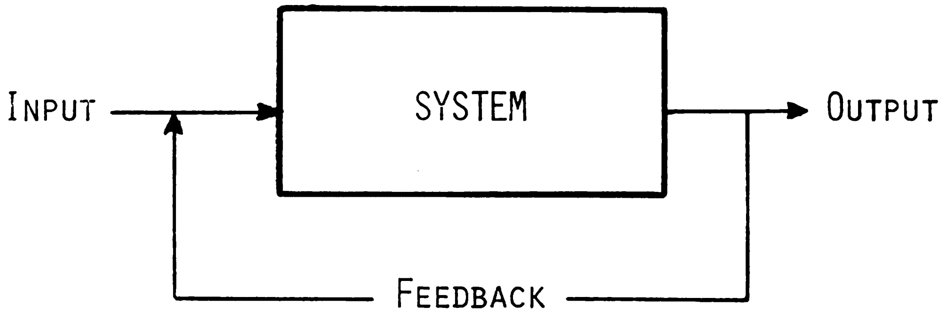

Figure 2. Simple System With Feedback Loop.

The Black Box Principle

Before proceeding to a discussion of ecosystems, it is helpful to examine a systems science concept called the Black Box Principle (Sutton and Harmon, op. cit.; Kramer and de Smit, op. cit.). A black box is an open system which responds to inputs as any open system would; however, what is inside the system performing the modifications is unknown. Beginning students in systems science operate a computer program in which a black box mathematically manipulates numerical inputs. The students then must predict what is happening within the black box. For example, if the number 4 is entered into the program and the output is 6, something in the black box may have added 2 to the input or may have multiplied the input by 1-½. If the output is 16, the input may have been squared or multiplied by 4; if the output is 2, the square root of the input may have been taken or the input may have been halved; and so on. The student may have some idea of what was happening within the black box, but he or she would not know the actual mechanism that was performing the manipulation. That mechanism would be called a subsystem of the black box.

Ecosystems

Ecosystems are the fundamental units in which the complex interactions between living things and their environment take place. Of all the categories in the hierarchy of physical systems, from universe to atom (Tansley, op. cit.), the ecosystem is the level at which those relationships can be described and studied directly. Figure 3 shows a general representation of the hierarchy of physical systems. It can be seen from the diagram that levels above the ecosystem (e.g., biosphere, planets, etc.) become increasingly more general while levels below the ecosystem (e.g., community, population, organism, etc.) are not only more specific, they do not include the biotic-abiotic interface found in ecosystems. Because ecosystems are open, natural systems, they require energy inputs via sunlight and chemical bonds. The interconnections between living things and their environment feature the necessary exchange of resources for growth and reproduction. These interrelationships form a dynamic, self-perpetuating complex (Tyler, op. cit.). Ecosystems may be conceived and studied in various sizes as long as the major components are present and operate together to achieve some sort of functional stability for any time interval (Odum, op. cit.).

UNIVERSE

PLANET EARTH

BIOSPHERE

ECOSYSTEM

COMMUNITY

POPULATION

ORGANISM

MACROBIOLOGY ------------ ECOLOGY

MICROBIOLOGY

ORGAN SYSTEM

ORGAN

TISSUE

CELL

ORGANELLE

ORGANIC COMPOUNDS

MOLECULE

ATOM

SUBATOMIC PARTICLE

FIGURE 3. THE HIERARCHY OF PHYSICAL SYSTEMS (AFTER TANSLEY, 1935).

Ecosystem Components

The major functional components of ecosystems are abiotic (nonliving) and biotic. Abiotic components are basic inorganic and organic compounds of the environment which are the resources necessary for life. Life can exist only within the earth's biosphere, or that portion of the air, water, or land where conditions are favorable for life. If the earth were represented by an apple, the biosphere would be as thin as the skin. Figure 4 is an illustration of the abiotic and biotic components as they are arranged within any ecosystem. Biotic components make up all of the communities of living things which interact with the nonliving habitats of the biosphere.

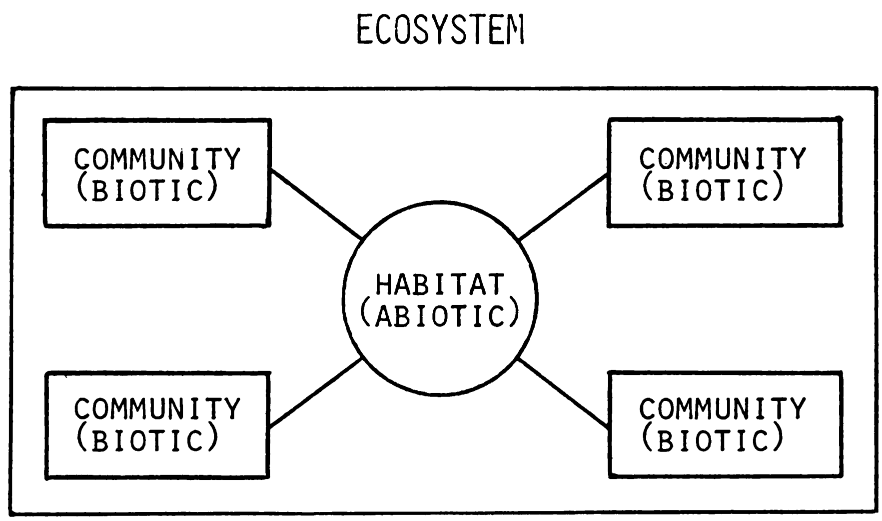

FIGURE 4. THE BASIC ECOSYSTEM - GENERAL INTERCONNECTION BETWEEN ABIOTIC COMPONENTS (THE HABITAT) AND BIOTIC COMPONENTS (COMMUNITIES) IN ANY GEOGRAPHICAL LOCATION.

The populations of living things - plants, animals, bacteria, and fungi - are collectively arranged within communities, the biotic portion of ecosystems. Populations within a community are classified or arranged according to the trophic structure, which functions to distribute energy and nutrients from the habitat to all living things. These structural components are actually nested subsystems within the overall ecological system. Interconnections between the subsystems provide control and maintenance (these will be examined in more detail in Chapter Three). Figure 5 shows a further breakdown of any community as seen in the previous figure (Figure 4). Each community is composed of populations of producers, consumers, and decomposers arranged around the trophic structure. The trophic structure is examined in greater detail in the next figure (Figure 6), which shows the basic pathways of energy and matter as they are being utilized by living things (Thomas, et. al.; 1978; p. 24).

Biotic components of communities are either autotrophic or heterotrophic organisms. Autotrophs are the producers - the plants which fix light energy, use simple inorganic compounds and build complex organic substances through the process of photosynthesis. The sun is the basic lifegiver to the earth; only green plants are able to convert solar energy into primary biomass, which can then be used by heterotrophs. The general photosynthetic process is:

$$6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

carbon dioxide + water → organic sugars + oxygen + water

Heterotrophs, including both consumers and decomposers, do not have the ability to utilize sunlight for anything but heat and light. They must

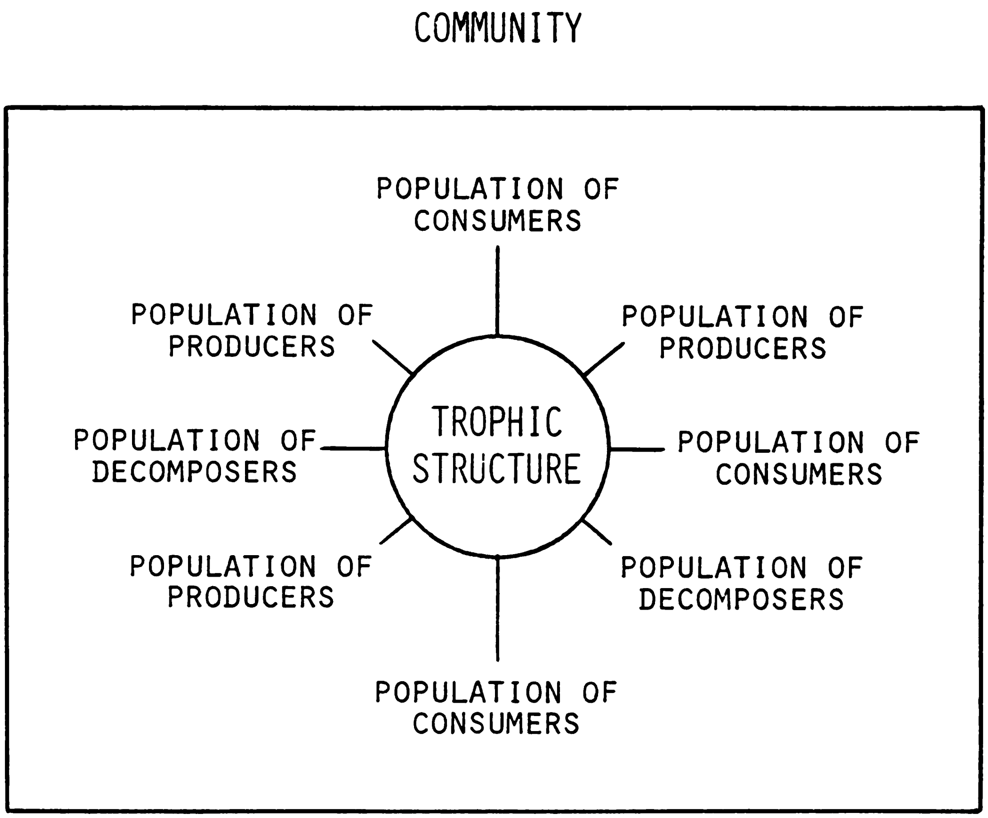

FIGURE 5. THE BASIC COMMUNITY - ALL POPULATIONS OF ORGANISMS MAKE UP A COMMUNITY AND ARE LINKED TOGETHER THROUGH THE TROPHIC STRUCTURE (OR FOOD CHAIN); THE MECHANISM BY WHICH THEY OBTAIN NUTRIENTS AND ENERGY DETERMINES WHETHER THEY ARE PRODUCERS, CONSUMERS, OR DECOMPOSERS.

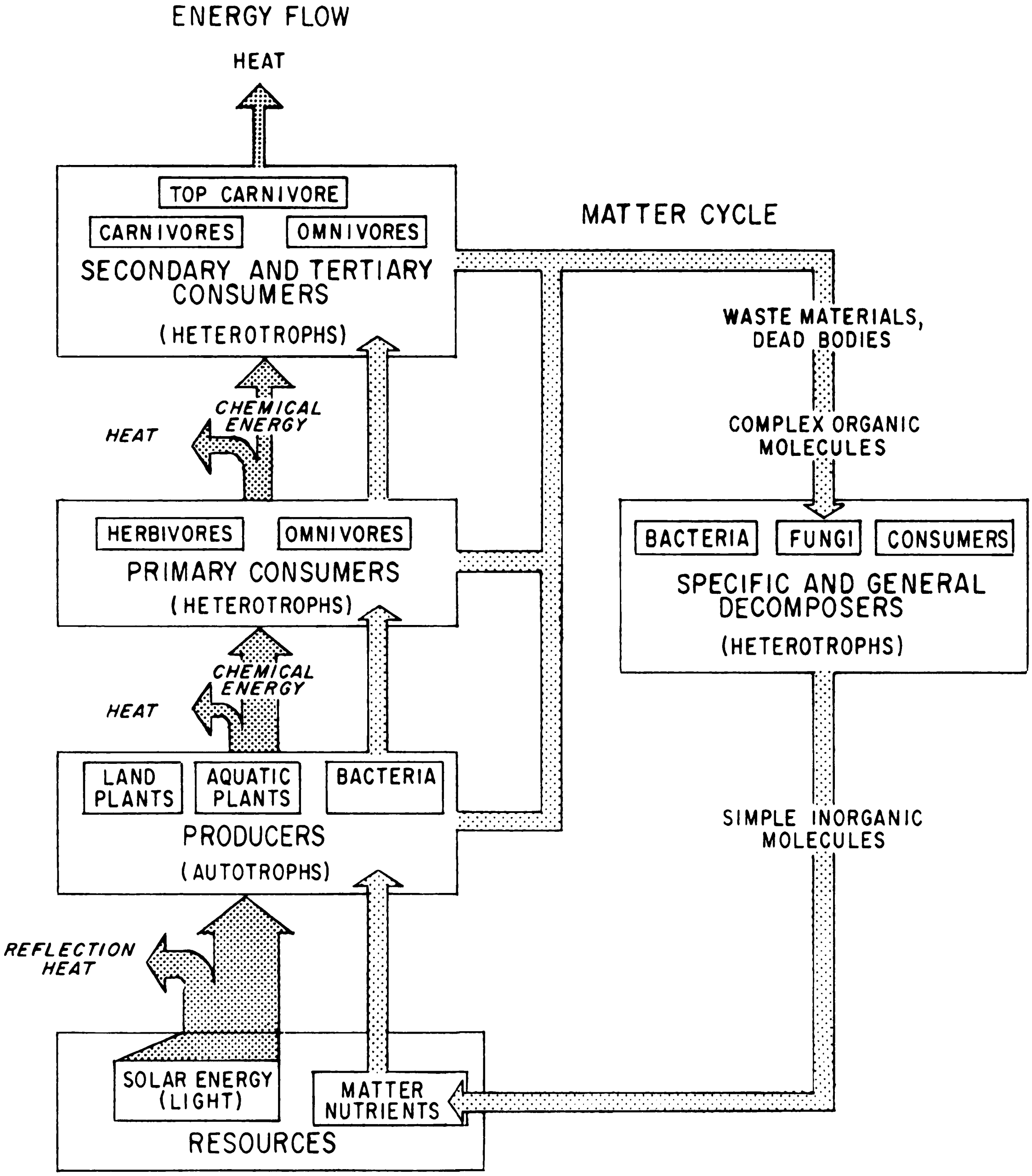

FIGURE 6. RELATIONSHIPS BETWEEN TROPHIC LEVELS AND ENERGY AND MATTER USE - ENERGY FLOWS THROUGH THE SYSTEM WITH LOSS OF UTILITY AND EFFICIENCY WHILE MATTER IS CONTINUALLY CYCLING (THOMAS, ET. AL., 1978; P. 24).

depend on plants to provide food, energy, and oxygen. When plant materials are ingested by primary consumers, the energy from the chemical bonds in the organic compounds becomes available to the organism. This energy, along with oxygen, helps recombine the nutrients from the food into new compounds that the organism needs for its life processes. If the primary consumer is, in turn, eaten by a secondary or higher-order consumer, its structural components are available for use by the subsequent consumer. Waste products from respiration or digestion and dead plant and animal remains are fed upon by decomposers (usually smaller organisms which break down the complex organic compounds into their inorganic components). Thus, the cycle has returned to its starting point, with raw materials again available for primary productivity.

The amount of food or nutrients available as the result of primary and secondary productivity is termed biomass. Biomass is usually considered to be the standing crop, which is the amount of living organic material present in the ecosystem at any particular point in time. In the black box model of the ecosystem, inputs of energy and matter cross the system boundary and are converted by productivity (photosynthesis) to create the output of biomass. (It is understood that one of the subsystems of the ecosystem is the activity of green plants.) Biomass, because of its potential for future nutrients, operates as part of a feedback loop.

There are other ecosystem responses of importance under the general heading of homeostasis, or dynamic equilibrium (Cannon, 1939). Homeostasis is the so-called "balance of nature" in which negative feedback allows an ecosystem to maintain stability over long periods of time. In a general sense, there is usually enough plant food produced yearly to allow consumer growth and reproduction, predators to cull surplus organisms, and conditions for decomposition to return sufficient nutrients for plant growth. The presence of homeostasis and other ecological processes keeps the living portion of the ecosystem in balance or equilibrium with the constraints of the environment. Under natural conditions, there is usually sufficient output (biomass), living space, and abiotic raw materials to maintain maximum populations of all producers, consumers and decomposers. This is called carrying capacity, an important concept for managing both natural and man-made systems. Carrying capacity is one of the more influential feedback mechanisms in ecosystems.

The interactions between biotic and abiotic factors within the ecosystem occur among the nested subsystems. There are four general (and complex) subsystems of any ecosystem: (1) trophic structure, (2) populations of organisms, (3) communities, and (4) habitat. Each subsystem is specifically identified in the general definition of an ecosystem: an open system with respect to material and energy flow (trophic structure) comprised of abiotic and biotic components (populations of organisms) in a geographical locale (habitat) whose interrelationships (community) are such as to form a dynamic, self-perpetuating complex. As in all systems, the lower level of resolution (subsystem) explains how the system works. By examining the actions and interactions of each subsystem in greater detail, the functioning of the complete ecosystem can be understood.

Trophic Structure

Trophic structure (Figure 6) supplies the means by which energy and matter are dispersed throughout the ecosystem and utilized by all biotic components. Basically, this is done within the food chain. Light energy is fixed by green plants into the organic material forming their structure. Herbivores, or plant-eating animals, feed directly upon plants and utilize the stored chemical energy and organic material for their metabolism. Herbivores are known as primary consumers because they must depend on plants for their food. Secondary, tertiary and higher-order consumers are carnivores because they feed upon herbivores or other carnivores by capturing and killing them. Omnivores are less specialized in their eating habits, having the ability to utilize both plant and animal material. Finally, decomposers - both general (any consumer which breaks complex organic compounds into simpler ones; i.e., most consumers) and specific (consumers which break organic compounds into their inorganic components; usually bacteria and fungi) - complete the cycle. Each link of the food chain comprises a trophic level.

A food web, usually the result of several interlocking food chains, is established when there are several representatives of each trophic level present in a given ecological situation. The food web contains more individual organisms in each trophic level than a food chain to allow for more efficient use of the available energy. The division of matter and energy relationships into set trophic levels is by no means rigid. Whittaker (1975) points out that many animals take food that is suitable in size range and other characteristics and, consequently, food is taken from more than one trophic level.

The amount of energy and matter available to the ecosystem is dependent upon the rate at which plants are able to transform light energy into biomass, or the amount of food material needed to support a population. This energy storage is accomplished through primary and secondary productivity. There is, however, a loss of available energy through each successive trophic level. This inefficiency of energy transfer is due to the first and second laws of thermodynamics: energy cannot be created nor destroyed but may be transformed from one form to another and only if it is degraded or dispersed. Only 2 percent of the light radiated by the sun is absorbed by the leaves of green plants; the rest is reflected back into space. Half of the absorbed light is used during photosynthesis, making the process only 50 percent efficient. The remaining energy is used during plant respiration and given off as heat. Therefore, only 1 percent of the total solar energy reaching the earth is available to consumers. From there, only 1/10 of the total energy available to each trophic level is utilized while the excess is lost as heat during respiration. The higher in the trophic structure (further away from the primary productivity of green plants) an organism is, the less energy is available to that organism. Thinking in terms of biomass, it would take 100 pounds of plant material to produce 10 pounds of a primary consumer or herbivore. That 10 pounds would convert to only 1 pound of a secondary consumer (in this case, a carnivore). If a larger or top carnivore ate the lower-order carnivore, it would be able to add only 1/10 of a pound to its body weight. An omnivore, on the other hand, has the ability to utilize both plant and animal protein, although it is utilizing the stored energy more efficiently when it eats plant material.

The study of trophic levels is useful in understanding the food relationships in communities. The availability of suitable food sources is one of the more important factors in determining the ability of a habitat to support populations of organisms. A highly productive ecosystem (such as a salt marsh, an estuary, or a deciduous forest) will usually have a large and diverse animal population associated with it. Such an ecosystem will also tend to support a wide variety of niches (or the specialization of a species in relation to other species). Low-productivity areas (such as deserts with less than five inches of rainfall or the infertile open ocean) will have relatively few species of animals and plants associated with them.

Populations

A <u>population</u> of organisms (Figure 5) consists of all the individuals of one species occupying a portion of an ecosystem at any one time. This could include all of the bluebirds living in an orchard, all of the bass in a lake, or all of the dandelions in a neighborhood. This is in contrast to a community which includes every individual of every species which exist in an area.

There are many factors which determine why a population is present within an ecosystem, what its size is, and whether its numbers are static, increasing, or declining. Krebs (1972) lists dispersal (accessibility of an area), behavior (habitat selection), the influence of other species, and physical and chemical factors as major determinants of a species' presence in any particular area. The quality of the environment, specifically carrying capacity, will determine the density, relative abundance, and change over time of a population.

Populations of organisms are found on the various levels of a food chain. They help determine how energy will flow through the system and at what rate matter will be cycled. In turn, organisms are dependent on the environment for the energy and nutrients necessary for growth, metabolism and reproduction. The environment provides the niche, which is the functional status of an organism within its ecosystem due to the morphology, physiology, and behavior of the organism. Niche refers to the specialization of a population within the community, and each species has its distinctive niche area. Much of the occupation of an organism is in search of food; therefore, a niche is often identified via the food relationship.

The density, distribution and adaptability of a population will depend to a great extent on the availability of its niches and the variety and abundance of other requirements such as shelter, water, sites for reproduction, and so on. The presence or lack of the requirements for life will determine the population size and whether that population is healthy or failing.

Population dynamics is represented by a simple formula that the rate of population increase is determined by the amount of new individuals added to the population (natality + immigration) minus those which leave the population (mortality + emigration). Due to its biotic potential, a population will increase as long as there are resources available for its survival. The upper limit of resource availability is the carrying capacity, which is determined by the rate of productivity, amount of biomass, available niches, and habitat or living space. The size of a stable population in any one area will be determined by its ability to stay within the carrying capacity. If the local abundance of a population exceeds the carrying capacity, it must be lowered by reducing the population size. In natural systems, this is done by an increasing death rate or decreasing density through dispersal. In artificial systems, man has increased his supply of food and other resources with the hope of continually raising the carrying capacity. Inflation and increasing shortages of food, energy, and materials may be an indication that human systems are approaching or even exceeding carrying capacity.

Communities

Communities (Figures 4 and 5) are the living parts of ecosystems and are made up of all the populations and individuals living in a physical habitat. Some communities are large enough to produce their own food and, therefore, are independent of other communities. Most communities, however, are dependent upon interactions with adjoining communities. Whittaker (op. cit.) defines a natural community as an assemblage of populations of plants, animals, bacteria, and fungi that live in an environment and interact with one another, forming a distinctive living system with its own composition, structure, environmental relations, development, and function. An oak forest community may contain oak and other species of trees, shrubs, low-growing herbaceous plants, birds, mammals, insects, microorganisms, and many other living things held together by their interactions with each other and with the environment.

In the above example, the community was named an oak forest because oak trees were the most dominant species observed in that locale. Although there are usually many more species of plants and animals present in a community, identification and classification of a community is simplified by naming the community after the species most common, abundant, or conspicuous. In most cases, this is the dominant plant species. Other attributes for classifying communities have included geomorphic characteristics, climatic factors, and functional relationships. Examples include tall-grass prairie, tropical rainforest, tidepool, and fertile agriculture.

There are two major concepts relating to community ecology. The first deals with interspecific relationships and interdependence of the organisms found in a community. The second pertains to community dynamics and, specifically, succession or orderly change over time.

Because of the constraints and limitations on the transfer of energy and matter by the trophic structure and the physical environment, organisms must compete with each other for the materials or space essential for life. Interactions which ultimately influence the growth and survival of populations are the result of organisms interfering with each other (such as competition, predation, or parasitism), assisting each other (symbiosis), or having no observable effect.

Competition, predation, and parasitism are designated as negative species interactions. Competition between species or populations is due to limitations in carrying capacity, available niches, and natural selection. The species which is able to compete most successfully for essential life requirements will do so at the expense of other species. Likewise, predation and parasitism are negative interactions in that one species is destroyed to benefit another. Positive interaction, or symbiosis, occurs when either one or both species of a relationship benefits through the association, but not at the other's expense.

Symbiosis includes commensalism (when one species benefits), protocooperation (when both species benefit), and mutualism (occurring when both species benefit and are actually dependent on each other).

Community dynamics is a concept which examines the overall structure and function of a community or of all of the populations existing together. It looks at how communities form and change over time. Ecological succession is the orderly process of community change. A community will form in an area depending on physical factors such as soil (or substrate) and climate. Succession is directional; once a community has established itself, it rarely remains unchanged unless physical conditions prevent the replacement of present populations with subsequent ones. An established community can actually modify its environment by altering the soil composition or microclimate in such a way that new species are able to exist in the area. Eventually, the new species will dominate the community, and so on. Each change in community composition is called a seral stage and each seral stage has its associated populations of producers, consumers, and decomposers. Eventually, a community will reach equilibrium with its environment, succession will become stabilized, and the community will tend to replace itself over time. A self-perpetuating or ultimate community has reached the climax stage and will remain as such until there is a physical change in the environment which the community cannot adapt to. The climax stage will tend to have the most stable trophic structure, provide the most niches, be the most energy- and material-efficient, and be most resistant to disruptive change.

Habitat

Just as the niche describes how a species utilizes its environment, the abiotic habitat (Figure 4) describes where a species is normally found in the environment. There are three general habitats within the biosphere: marine, freshwater, and terrestrial. An organism's living area is that specific portion of the habitat which contains its niche. All trees are terrestrial, but each species of tree has certain requirements for soil, moisture, temperature, and sunlight which limit where that tree can exist. Therefore, plants are dependent largely on the abiotic portion of the ecosystem as their habitat. This generalization also holds for consumers, but since consumers ultimately depend on plants for food and energy, plants must be considered part of the consumer's habitat.

Not only does habitat provide the energy and nutrients necessary for life, it also supplies the shelter which organisms need for daily and seasonal movement, secure sites for rearing offspring, and protection from predators. Limitations in the habitat will place limits on the carrying capacity, species and population interactions, and community succession. Habitat also influences the diversity of organisms which, in turn, tends to stabilize the ecosystem. Diversity differences within a given habitat-type reflect the partitioning of available niche space within habitats (Pianka, 1978). Basically, more niche partitioning allows for a greater variety of organisms and a greater amount of variability in niche utilization within each trophic level. A rich and varied habitat will allow utilization of its niches during daily and seasonal periods and at different levels of space within the habitat. For example, nocturnal and diurnal animals may occupy the same niche, although at different times; certain species of birds will occupy niches at different heights of a tree.

Organisms which can control their habitat to any degree have the ability to alter community succession which will determine how, and by what species, a habitat will be utilized. During any particular successional stage, there will be dominant species of plants utilizing the nutrients provided by the soil and producing food at a rate determined by the sunlight available to the habitat. If physical conditions remain constant, the plants will add humus to the soil, provide shade, modify humidity and temperature, and reduce wind velocity. These plants will provide food and shelter for animal and additional plant species. Unless the community is at climax or physical conditions change, succession generally proceeds according to prediction. Animals have also been known to affect habitat, specifically in those instances where there is over-utilization and subsequent reduction of plant species. For example, overgrazing in short-grass prairies of the American Southwest has led to the loss of such habitats in favor of desert vegetation.

Conclusion

The purpose of Chapter Two was to present a general model of ecological systems (or ecosystems) from a consolidation of systems theory, ecological concepts, and basic premises of natural science. Although the study of ecosystems is only a small part of the overall discipline of ecology, the ecosystem level of natural and artificial systems is an important one from the standpoint that both abiotic and biotic components are accessible for both study and management at the ecosystem level. By adapting a systems approach throughout the chapter, the complex components of ecosystems could then be isolated and defined. Once the structures and functions of an ecosystem are understood, the interconnections and interactions between them become more readily apparent, and the origin and mechanism of such activities can be seen and studied as they actually occur.

The intention of every ecologist or student of the environmental sciences is to formulate and test an ecosystem model which conforms with reality. Advances in ecological research have given scientists a good idea of what is already happening in the environment; an accurate ecosystem model will give scientists and decision makers the ability to predict what will happen in any future interaction. Specific ecosystem models have become standardized, but complete and comprehensive models are still being hypothesized. A continued combination of the systems and natural sciences will be invaluable in the formulation of workable models with valid predictive powers for use in ecosystem monitoring, evaluation, and management.

Chapter Three describes the complex ecological principles by which all ecosystems, whether they are natural or human-influenced, are governed. Ecologists are able to use ecological principles in the formulation of models which are of value in studying and predicting ecological processes. The principles are arranged according to naturally occurring cycles, and models of these cycles are illustrated. A generalized ecosystem model has been created to show the complex interactions which occur within any ecosystem.

CHAPTER THREE

ECOLOGICAL PRINCIPLES

Introduction

Ecologists describe and study the components and interactions within ecosystems for the purpose of formulating an accurate predictive model. Criteria of such a model includes the development, analysis, and evaluation of ecological hypotheses based on field work and research. In addition to gaining knowledge, the major purpose of establishing criteria is to develop the ability to manage and manipulate natural ecosystems for their intrinsic value as well as for the resources they provide to functioning human systems. Specifically, understanding ecological criteria in ecosystem management is important in land type and use classification; resource development and planning; protection and preservation of ecosystem types; and the control of environmental degradation.

The interpretation, analysis, and evaluation of ecological criteria or hypotheses can be approached by examining each process as part of a series of principles. In other words, there are certain "ground rules" which have become established through ecological study. Although most of the principles have yet to achieve the status of scientific law, they are inherently vital to any human interaction with natural ecosystems. Such principles must be understood and generally accounted for in order to study, understand, and manage ecosystems.

Explanation of Ecosystem Cycles

Ecosystems contain fundamentally circular processes and are subject to numerous feedback effects (Commoner, 1970). Their responses to environmental effects (or human perturbations) will tend to remain circular, or homeostatic, as long as feedback continues to be negative. Described in this chapter are four models of circular processes - energy-matter, population, community, and abiotic-biotic - which are governed by ecological principles and which occur within all ecosystems. Each cycle represents certain ecosystem subsystems and their associated interactions. The interactions between ecosystem components and processes proceed until homeostasis, or dynamic equilibrium, is attained. Equilibrium within ecosystems over a relatively long period of time will provide an appearance of stability, although most ecosystems are not static.

The four ecosystem processes, therefore, represent four homeostatic cycles. These cycles will remain cyclic or circular as long as interactions between components and processes contain negative feedback. All ecosystems have a disruptive threshold where homeostasis can be destabilized through natural or human disturbance, although system responses will remain circular. These homeostatic cycles include energy and matter, habitat, community, and population. The cycles were formulated by taking ecosystem processes and components introduced in Chapter Two and arranging them in appropriate order to demonstrate what occurs in the interactions between living things and their environment.

The arrows represent interactions which occur allowing the system to proceed toward dynamic equilibrium. Each box represents an important process which must occur before the next process can proceed; or it may represent a reaction of a component to a preceding environmental constraint. For purposes of clarity, the component which is symbolized by a box in each figure will be underlined in the text. The description will provide an understanding of how each component is affected by a preceding process and how it, in turn, affects those processes which follow it. The complete cycle is homeostatic and enduring. In addition, when all of the cycles are combined, it can be demonstrated that there are no ecosystem processes or activities which occur independently of each other - everything tends to affect everything else.

By carefully studying the cycles within ecosystems, an understanding of the interrelationships present in all ecosystems can be achieved and used in establishing ground rules for ecosystem management. Each cycle will be examined individually to obtain a set of ecological principles which can be applicable to ecosystem planning and management.

Energy-Matter Cycle

Before proceeding into a discussion of the Energy-Matter Cycle in Figure 7, it must be noted that, in functioning ecosystems, energy does not cycle in the same sense as matter does. Energy flows through the system: entering as light, being transferred through the trophic structure in chemical bonds, and leaving the system as waste heat from respiration. Energy is included with matter in the ecological cycle because the two represent a combination of available resources which all living things require for survival (refer to Figure 6 in the preceding chapter).

Matter continually moves or cycles through the ecosystem in biogeochemical cycles, which include the hydrologic, nitrogen, phosphorus, and carbon cycles. Inorganic and organic compounds continually circulate between living things and the environment in the form of nutrients, food, and waste materials. Some compounds may be held for long periods of time in the bodies of organisms, within rocks or soil, or deep in the ocean, while others, like carbon, are rapidly turned over during processes such as photosynthesis. These materials provide the requirements for survival (of all the known elements which occur naturally, nearly forty are required by organisms), and all are used as they become available, either through the food chain or directly from the environment. Therefore, the presence or absence of the minimum quantity of any material essential for life becomes a limiting factor. If a material is present and in usable form, life can occur in that particular habitat.

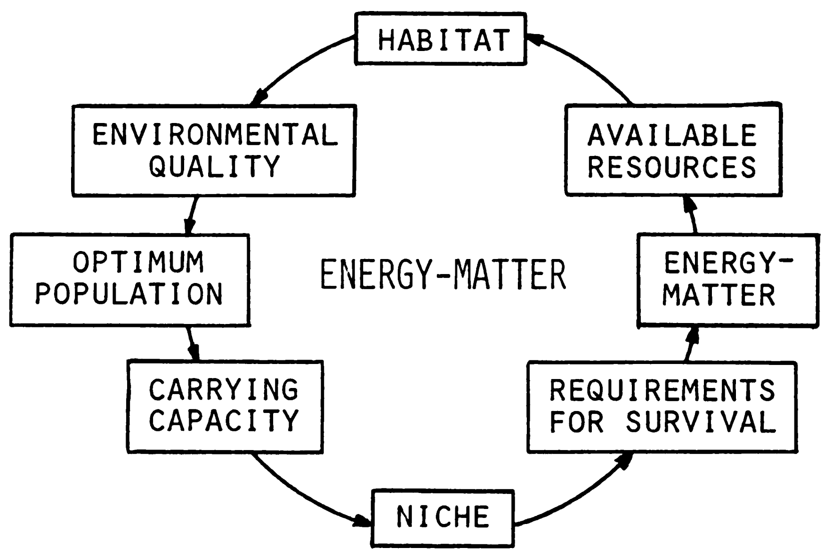

FIGURE 7. THE CYCLING OF ENERGY AND MATTER WITHIN THE ECOSYSTEM.

Each of the resources provided by the habitat can be limiting. These include food, water, shelter, and proximity to other members of each species, which is necessary for reproduction. A sufficient quantity of resources for a particular species in a habitat will, in turn, provide that species with a niche, or a position within the ecosystem. Although conditions favorable toward establishment of a niche do not ensure that the niche will be occupied, competition among organisms for resources will tend to fill available niches. The niche available to large herbivores in the tall-grass prairies of the American Midwest was largely vacated through reduction of the vast herds of bison, only to be refilled by domestic beef cattle as a result of human manipulation.

The level of carrying capacity is directly proportional to the overall health (relative abundance of resources) of the habitat. As more abiotic and biotic resources are available, a greater variety of niches becomes attainable which will enhance carrying capacity (in this case, distribution of materials and energy) of a particular habitat. Carrying capacity, in turn, limits the ability of a habitat to support an optimum population. A population will change or fluctuate according to the carrying capacity of the habitat. As resources become available in greater amounts, populations will increase to utilize them through increases in natality (birth rate) or immigration. The opposite (mortality and out-migration) occurs as population numbers exceed the ability of the habitat to make resources available for use. Optimum population levels become established when there is a balance between production and assimilation of food materials and when the variety of niches is filled.

Reasons for and why a population is changing are indications of environmental quality. Under natural conditions, a growing population may demonstrate that the carrying capacity limit has not been reached, while a decreasing population could be an indication that carrying capacity has been exceeded. On the other hand, either change could also be symptommatic of a population fluctuating around the carrying capacity or that serious ecological problems may be present within the system. An oft-quoted example is that of algal blooms in eutrophic lakes. An overabundance of phosphate will lead to a population explosion of algae. As the algae grow and die, oxygen is required in the decomposition of the organic detritus. The percentage of dissolved oxygen in eutrophic lakes is usually low (less than 7 parts per million), and this low percentage of oxygen is rapidly used up during decomposition. Anaerobic decomposition, performed by bacteria which do not require oxygen, then takes over, usually with the production of waste materials which may be either noxious or toxic to other organisms.

Other parameters of population change due to environmental quality include age distribution and population dispersal. A population with a relatively large number of young individuals will exhibit an increasing birth rate and subsequent demand on materials and energy. As the carrying capacity is approached or exceeded, the demands on the environment will cause a reduction in environmental quality. Population decrease, either through high mortality rates, decrease in birth rates, or dispersal of the population to other areas, will allow the environment to recover. Completing the circle, the quality of the environment is determined by population demand for materials, energy, living space, and so on, which determine the overall health or carrying capacity of the habitat to support those populations.

Population Cycle

As shown in the discussion of the Energy-Matter Cycle, the presence and quality of populations of organisms is dependent upon resources provided by the habitat and, ultimately, upon the carrying capacity. The availability of resources is one of three factors which determine both population density and development; the other two are biotic potential and environmental resistance. Environmental resistance will be discussed later in this section. The Population Cycle in Figure 8 is connected to the Energy-Matter Cycle at the carrying capacity component box.

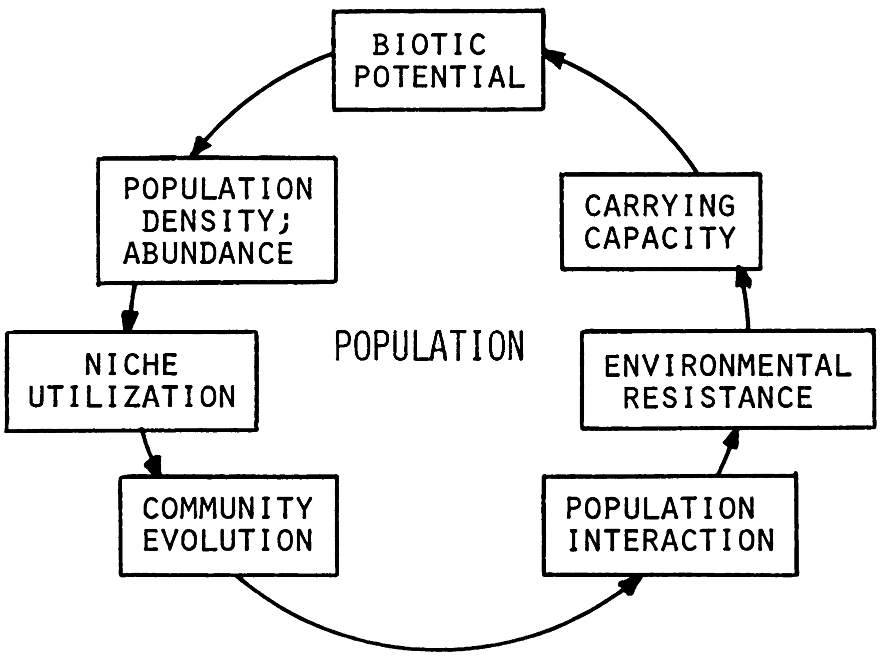

FIGURE 8. POPULATION CYCLE.

According to Odum (1959, 1971), biotic potential in organisms is achieved when the growth rate (population growth rate per individual) becomes constant and maximum for the existing microclimatic conditions. Theoretically, this can occur only when the environmental carrying capacity and other factors (space, food, lack of competition for resources, etc.) are unlimited. Factors contributing to the calculation of biotic potential are the age distribution and the growth rate of each age group. Actually, the term "reproductive potential" would be a more descriptive term because "biotic potential" has been widely used to describe true population increase within carrying capacity constraints, although this is not the case since carrying capacity nearly always prevents a population from ever achieving its true biotic potential.

Biotic potential will determine the population density in an ecosystem by filling it with new individuals. A portion of an ecosystem which contains the right kinds and amounts of resources will tend to have a more dense population. In those areas, therefore, there will be a higher relative abundance of both individuals and populations. In areas of nutrient richness, such as marine upwellings and estuaries, there will also be concentrations of many species of both producers (phytoplankton) and consumers (zooplankton, fish, marine mammals, etc.). Such areas are not only important feeding grounds, they also tend to be the breeding centers of many species. Populations are both abundant and dense in such areas, and the true biotic potential is most closely realized. In areas where populations or species are widely dispersed as a result of resource or space limitations in the carrying capacity, biotic potential may be more severely limited as well.

Community Cycle

Figure 9 models what occurs when population interaction and physical processes (abiotic factors) interact to cause successional changes within a habitat and its associated communities. A major kind of community on a given continent is a biome. A biome is a grouping of terrestrial ecosystems that are similar in vegetation structure, in the major features of environment to which this structure is a response (specifically mean annual rainfall and temperature), and in some characteristics of their animal communities (Whittaker, 1975). Local variations within each biome-type are generally dependent upon microclimatic conditions and the influencing effect of individual populations. These two factors work together to bring about environmental modification, which leads to sequential population and community change known as succession.

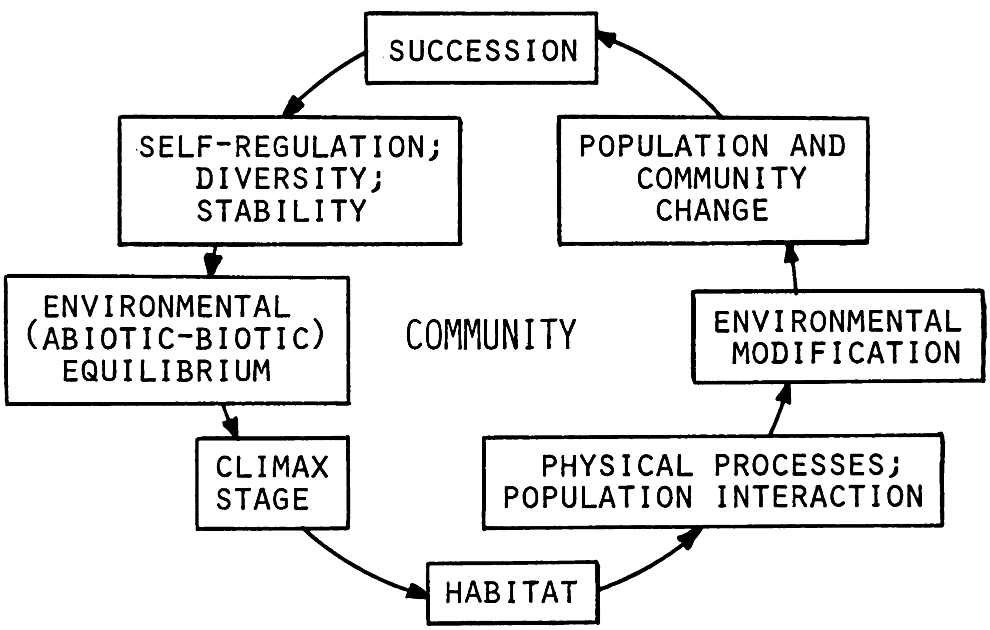

FIGURE 9. COMMUNITY CYCLE.

The presence and abundance of populations in a habitat will also influence niche utilization and community evolution or succession. A dense and abundant population will usually fill nearly every available niche in its efforts to survive. Competition for niche space can become fierce in crowded situations. On the other hand, dispersed populations have a surplus of niches to fill, and such niches may become available to adaptable individuals of other species. Ecologically dominant species or populations can exert a controlling influence upon communities by their size, numbers, or activities. If certain herbivores have increased their numbers enough to defoliate and kill plants they utilize for food, conditions may change sufficiently to allow the growth of different species of plants. This has happened during insect infestations when the dense leaf canopy was removed long enough to allow light penetration on the forest floor and release lower-story vegetation. Natural succession in ponds and lakes, or eutrophication, has been accelerated when aquatic plants experience rapid growth due to increases in nutrient input. Rapid accumulation of organic detritus will contribute to the natural filling of those bodies of water.

Much of this community evolution depends on associated interactions of abiotic factors, such as changes in climate or available sunlight, and a sufficient amount of time. Under natural conditions, the unbalancing effect of large populations is usually mitigated over time. Community evolution is normally a very slow process where change is in dynamic equilibrium with stability. Human activities, on the other hand, have often contributed to more rapid change without the inherent stability of natural systems. Manipulation of population density and abundance has led to changes in both community structure and biotic potential. The classic example is the elimination of a predator species from its niche of controlling an excess population of herbivores. The previously mentioned example of insect infestations and subsequent community change is often the result of such manipulations.

As a community evolves, there is a parallel evolution within the available niches with a subsequent modification of population interaction. Former niches are eliminated as new ones are created; adaptive species replace those which cannot tolerate the new conditions. Population interaction is a form of environmental resistance, or the sum total of environmental limiting factors which prevent the biotic potential from being realized (Chapman, 1928; Odum, op. cit.). Environmental resistance limits the carrying capacity by placing restraints on utilization of resources by organisms. Forms of population interactions which lead to environmental resistance and ultimately affect biotic potential can result in positive and negative interspecific interaction.

Positive interactions occur when two species live together without harming one another; this is known as symbiosis. Symbiosis includes (1) protocooperation (both species benefit by "cooperating" with each other in obtaining food or protection), for example, small birds picking the teeth of crocodiles; (2) mutualism (both species are completely dependent upon the relationship and would not survive without the other) such as that found in lichens, consisting of an alga which provides food and a fungus which lends supportive structure; and (3) commensalism (one species benefits while the other is unaffected), for example, cattle egrets which feed on insects and amphibians disturbed by grazing cattle, although the birds do not benefit the cattle by ridding them directly of parasites. Community change or manipulation which eliminates one species of a symbiotic relationship may cause the extinction of the other.

Examples of negative interactions, where one species benefits at the expense of the other, are readily observed and widely studied. Although a complete understanding of the mechanisms of interaction has not been achieved, there is little question of the importance of competition and predation as factors of environmental resistance. Competition occurs when two or more species must use the same limited resources; it can be direct, as in aggression, or indirect by elimination of necessary resources. Because energy is expended in competing for resources, it is more advantageous for species to avoid direct confrontation. This has evolutionary importance by leading to niche separation, specialization, and diversification (Pianka, 1978).

Predation, on the other hand, usually occurs between trophic levels. A first-order carnivore captures and eats an herbivore while a higher-order carnivore preys upon both herbivores and other carnivores. The action of culling individuals from a population through predation has had an obvious effect on the biotic potential, although the effect is usually minimal where the interacting populations have had a common evolutionary history in a relatively stable environment (Odum, op. cit.). Natural selection assists both members of the relationship by favoring predators who are more successful at capturing prey and favoring prey species more adept at escaping or hiding from predators. Such positive traits tend to be incorporated into the genetic structure of each species, although the carrying capacity is the ultimate variable in population cycles as can be seen in Figure 8.

Community evolution, in which populations and niches change over time, was discussed in the previous section; however, a more complete description of the mechanism of succession is necessary here. Each time the environment (soil and microclimate) is modified by the interplay between the physical processes and an ecologically dominant population, a position is established for a second dominant population which eventually replaces the first, and so on.

Whittaker (op. cit.) outlines a number of trends or progressive developments which underlie most successional processes. As each trend is listed, an explanation will be given using examples from sand dune succession along the shores of Lake Michigan (after Cowles, 1899; Odum, op. cit.).

(1) There is usually progressive development of the soil, with increasing depth, organic content, and differentiation of horizons toward the mature soil of the final community. Primary succession on sand dunes begins in a relatively harsh environment with strong sunlight and winds and nearly sterile sands. Plants, such as grasses which are tolerant to those severe conditions, become established from wind- or animal-transported seeds. Their roots tend to hold and stabilize the shifting, wind-blown sand; as the plants grow, reproduce, and die, the organic material is held in the stabilized zone and continues to accumulate throughout succession.

(2) The height, massiveness, and differentiation into strata of the plant community increase. With the establishment of early successional stages, modification of the microclimate occurs; rooted plants break the force of the wind and provide shade.

This provides more favorable climatic conditions for less tolerant species which eventually replace the pioneer species. On the dunes, grasses give way to shrubs which, in succession, are replaced by cottonwoods; oaks and pines; and maples, beeches, and hemlocks. The beech-maple climax forest has the most well-developed stratification of any of the preceding seral stages.

(3) Productivity increases with increasing development of the soil and community structure and increasing utilization by the community of environmental resources. As the soil becomes deeper and richer, more plants are able to extract nutrients for growth; each seral stage becomes more productive. Increasing utilization of productivity by consumers will accelerate the turnover of nutrients through the trophic structure.

(4) As height and density of the plant cover increase, the species diversity increases from simple communities of early succession to the richer communities of later succession. Because of the harsh conditions found in early successional stages, there are relatively few organisms which can adapt to such conditions. Through succession and community change, such conditions are tempered with the decrease of direct sunlight and strong winds, the presence of more food (abundance of niches), higher humidity, and narrower temperature fluctuations. Organism <u>diversity</u> and <u>stability</u> increase as a result.

(5) Populations rise and fall and replace one another along a time gradient; the rate of this replacement slows through the course of succession as smaller and shorter-lived species are replaced

by larger and longer-lived ones. Although succession on sand dunes takes many years, the most rapid changes occur within the first successional stages. Plant species tend to be annuals and are characterized by a rapid turnover of their organic material, high productivity (but less utilization), rapidly growing populations, and higher vulnerability to sudden change. This leads to higher organism metabolism which requires smaller body size; the carrying capacity of that environment can support only the smaller organisms in any trophic level.

(6) Relative community stability increases; early stages contain populations which rapidly replace one another, while the composition of the final (or climax) community is self-regulating. The succession of beach communities along Lake Michigan has been proceeding for roughly 10,000 years. It may be assumed that present beech-maple climax forests have existed, relatively unchanged, for a large portion of those years and will continue to replace themselves into the future as long as climatic conditions prevail. Each earlier seral stage was present for a lesser amount of time along the 10,000-year continuum.

When a community and its processes have reached equilibrium with the environment, it has reached the final community or climax stage. A climax stage is self-perpetuating and tends to maintain such a state until physical conditions become permanently altered. The climax community will be the most stable and have the most population diversity due to its diversity of niches and complexity of its food web.

In looking at the community cycle from a human point of view, there are many places where the cycle can be and has been manipulated.

Environmental modification, whether physical, chemical, or biological, has caused changes in community succession. Agriculture reduces vast areas to early successional stages. Reducing species diversity through farming, forestry, and animal husbandry has led to instability as well as an elimination of natural communities. Upsetting environmental equilibrium and carrying capacity has limited the capacity of ecosystems to support populations of organisms.

Abiotic-Biotic Cycle

The processes taking place in the interplay between living things and their nonliving environment comprise the Abiotic-Biotic Cycle (Figure 10). Technically, these processes are important segments of the previously described cycles, but, due to their importance, a separate (though interconnected) cycle is proposed to examine the processes in more detail.

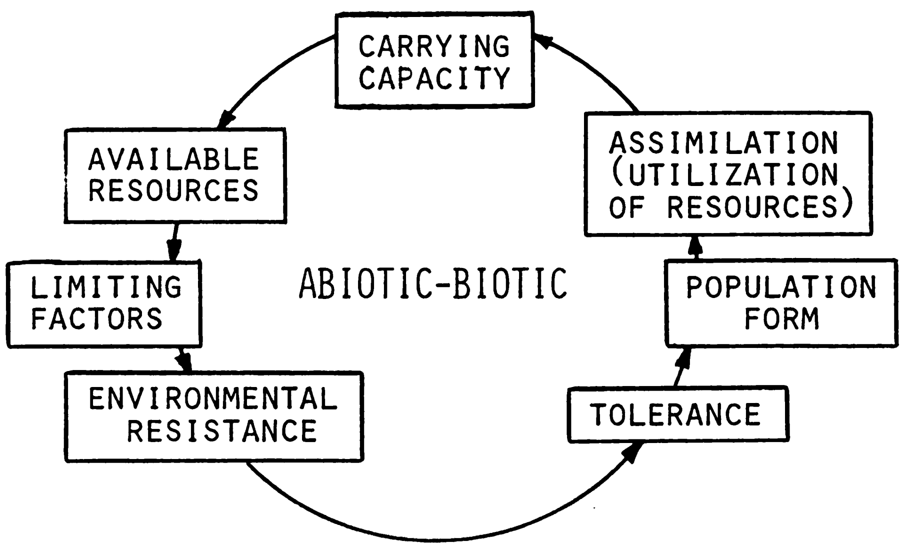

FIGURE 10. ABIOTIC-BIOTIC CYCLE - THE INTERACTION BETWEEN ORGANISMS AND THE ENVIRONMENT IN WHICH THE AVAILABILITY OF ENERGY AND MATTER IS LIMITING.

The habitat provides resources necessary for life. However, these resources (in this case, abiotic) may or may not be available in usable form or in sufficient quantities to permit the growth and reproduction of organisms. The presence or absence of environmental resources thus becomes a part of the limiting factors of environmental resistance to population growth, density, and distribution.

There are two ecological principles pertaining to limiting factors: Liebig's "law of limiting factors" (1840) and Shelford's "law of tolerance" (1913). The principle of limiting factors states that, to occur and thrive in a given situation, an organism must have essential materials necessary for growth and reproduction; the material amount most closely approaching the critical minimum tends to be limiting. Odum (1959; pp. 104-143) lists the following physical factors which may be limiting to organisms in an ecosystem:

(1) temperature;

(2) light radiation;

(3) water;

(4) temperature plus moisture (the role of climatic extremes);

(5) atmospheric gases (mostly in aquatic environments);

(6) macro and micro nutrients, such as organic material and trace elements;

(7) currents and pressures;

(8) soil;

(9) fire; and

(10) microenvironment, which can be a combination of all limiting factors exerted on a population or individual organism specifically where it is found.

The principle of <u>tolerance</u> states that the distribution and abundance of an organism can be controlled by factors exceeding the maximum or minimum levels of endurance for that organism. In other words, an organism's ability to tolerate limiting factors not only determines where it will be found but also how successful it will be in coping with the conditions (and resistance) of its environment. The chief limiting factor of most desert vegetation is the presence of water. Such vegetation is able to tolerate other conditions (temperature extremes, wind, soil salinity, etc.) and grow because it has adapted to drier conditions. Likewise, lack of direct sunlight may be limiting to species of plants in a forest understory. In this case, successful species are able to tolerate the limitations and are prepared to take advantage of increased sunlight when a canopy species dies.

Because of their complex interactions and inherent stability, ecosystems usually have more resilient tolerance levels than those of individual organisms. The effects of ecosystem manipulation are not always readily apparent, often not until the damage done represents irreversible change. Therefore, the study of indicator organisms can be important in understanding the context between manipulation and tolerance. Organisms with relatively narrow tolerance ranges to specific environmental factors make good indicator organisms. Inventory and monitoring of bird life has been proposed as an indicator of environmental quality. The presence or absence of certain species of aquatic life at measurable distances downstream of a sewage outfall has been used as an indication of both the stream's ability to assimilate organic waste materials and its overall water quality.

The population form of an ecosystem is dependent upon the ability of a species to tolerate environmental resistance and physical limiting factors. Population form includes those populations present, their age distribution, their density, and their rate of resource utilization or assimilation. Assimilation is the ability of a trophic level to convert energy and materials to biomass. This has a direct effect upon establishing the carrying capacity of an ecosystem. Carrying capacity is then a measure of the amount of resources available for use by living things. However, whether the biomass is produced and, ultimately, carrying capacity established are a direct measure of the ability of organisms to tolerate various environmental limiting factors and exist and grow in a particular environment.

Summary

Figure 11 is a simplified diagrammatic version of the complex interactions which occur in ecosystems. The cyclical interactions of Energy and Matter (Figure 7), Populations (Figure 8), Communities (Figure 9), and Abiotic-Biotic Processes (Figure 10) have been generalized and placed together to illustrate the inner workings of an ecosystem. Each combination of cycles was arbitrarily chosen because of commonly shared processes or components. In the diagram, carrying capacity is a component which is shared by the Energy-Matter and Population Cycles; habitat is shared by Energy-Matter and Community Cycles; and available resources is common to Energy-Matter and Abiotic-Biotic Cycles.

Closer inspection of each individual cycle will show that there are other components which are commonly found in a number of cycles. This indicates that there can be several cyclic combinations which are

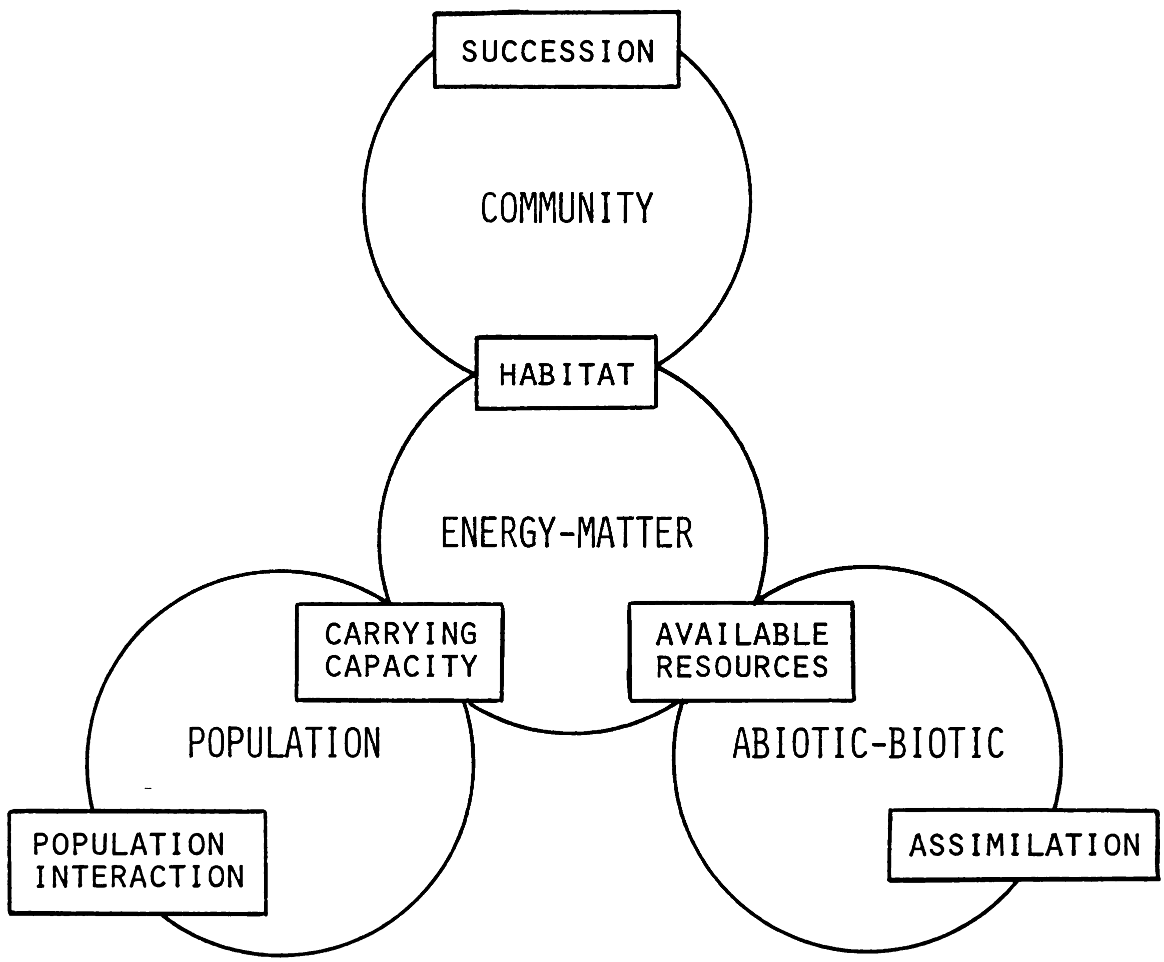

Figure 11. A Combination and Simplification of the Individual Cycles From Figures 7 Through 10 - a diagrammatic version of the cyclic nature of interactions occurring within any ecosystem.

achieved by simply moving each cycle model about. In living ecosystems, each process or interaction is so closely interconnected with others that to model such a system would prove difficult. For general, descriptive purposes, the next section of this chapter is an attempt to formulate a model of an ecosystem. An understanding of the cyclical nature of ecological processes and the closeness of the interactions among such processes will help validate an ecological model.

Modeling the Ecosystem

Various types of models have been used to describe, understand, and manipulate ecosystems. These include conceptual, diagrammatic, mathematical, and computer models (which are derivations of mathematical models). Tyler (1975) defines a model as a representation of a set of objects, attributes of objects, and the interrelationships existing among such objects and attributes, to a level of resolution, accuracy, and precision assignable by the modeler. Because all models exhibit varying degrees of abstractness, the modeler must decide the proper balance between realism and abstraction relative to the purpose of the model.

In order to be effective and valuable, an ecosystem model must have a combination of attributes including generality, precision, reality, utility, and wholeness. Developing a general conceptual model with a high degree of likeness to the real world will allow the model to be applicable in any ecosystem, whether large or small. The general nature will also yield a high degree of precision because the results of studying at an ecosystem level would be consistent and repeatable. It must be noted that this is not referring to mathematical precision;

it is practically mathematically impossible to include all ecosystem variables with any degree of precision. Most mathematical ecosystem models have to be limited to either small (and very general) ecosystems or to the interactions of a limited number of components. Such models, nevertheless, have been valuable research tools with a high degree of utility in serving their intended purpose.

The value of a state-of-the-art ecosystem model is in its reality and wholeness. An ecosystem is a real and important part of both natural and artificial systems. A model which includes a high measure of likeness to the real world and incorporates the essential variables responsible for creating the significant dynamics of the actual system has obvious attractiveness.

Chapters Two and Three have presented a series of conceptual and diagrammatic models which represent general ecosystems and their subsystems with increasing model complexity. Included are models of ecosystem components and trophic structure in Chapter Two and the Population, Abiotic-Biotic, Community, and Energy-Matter Cycles in the first part of Chapter Three. Each model has been designed to provide an understanding of ecosystem concepts and the principles governing ecological activities, interactions, and interrelationships pertinent to functioning ecosystems. Figures 12 and 13 diagram the overall conceptual model by placing ecosystem components and interactions in a double diagrammatic format.

Figure 12 is a state-of-the-art systems diagram of a complete ecosystem which includes feedback loops and interrelationships in some detail. It was developed from a combination of component models from Chapter Two and cyclic models from Chapter Three. The model itself is

Jacobs (1975; pp. 203-206) generalizes the major effects of human activities on ecosystems by examining their influences on ecosystem diversity, stability, and maturity. These effects include:

(1) transient perturbations, such as oil spills, chemical defoliants, fires, or poisonous spills in rivers, which cause short-term effects by resetting the succession clock;

(2) chronic shifts in environmental conditions including persistent toxic substances, cities, pavement, or dams, in which long-term or even permanent conditions are set forcing entirely new ecosystems;

(3) energy-nutrient relations represented by import into the system from outside (fertilizers, pollution, agricultural or technological management) or by export to other systems; in either case, the ecosystem must adapt to the net gain or loss; and

(4) manipulation of species, either accidentally or intentionally by importation, extermination, or habitat alteration.

Planning the Use of Ecosystems: Man and Nature

The purpose of this chapter has been to add the human element to the concept of ecosystem by recognizing that humans are integral to the inner workings of even the most remote and uninhabitable regions on earth. It is also recognized that even the least natural human ecosystem is still subject to the same ecological principles that govern natural systems. The idea here is that, because humans are part of the environment, they, their activities, and their artifacts must be considered in the planning and management of any ecosystem. Ecological

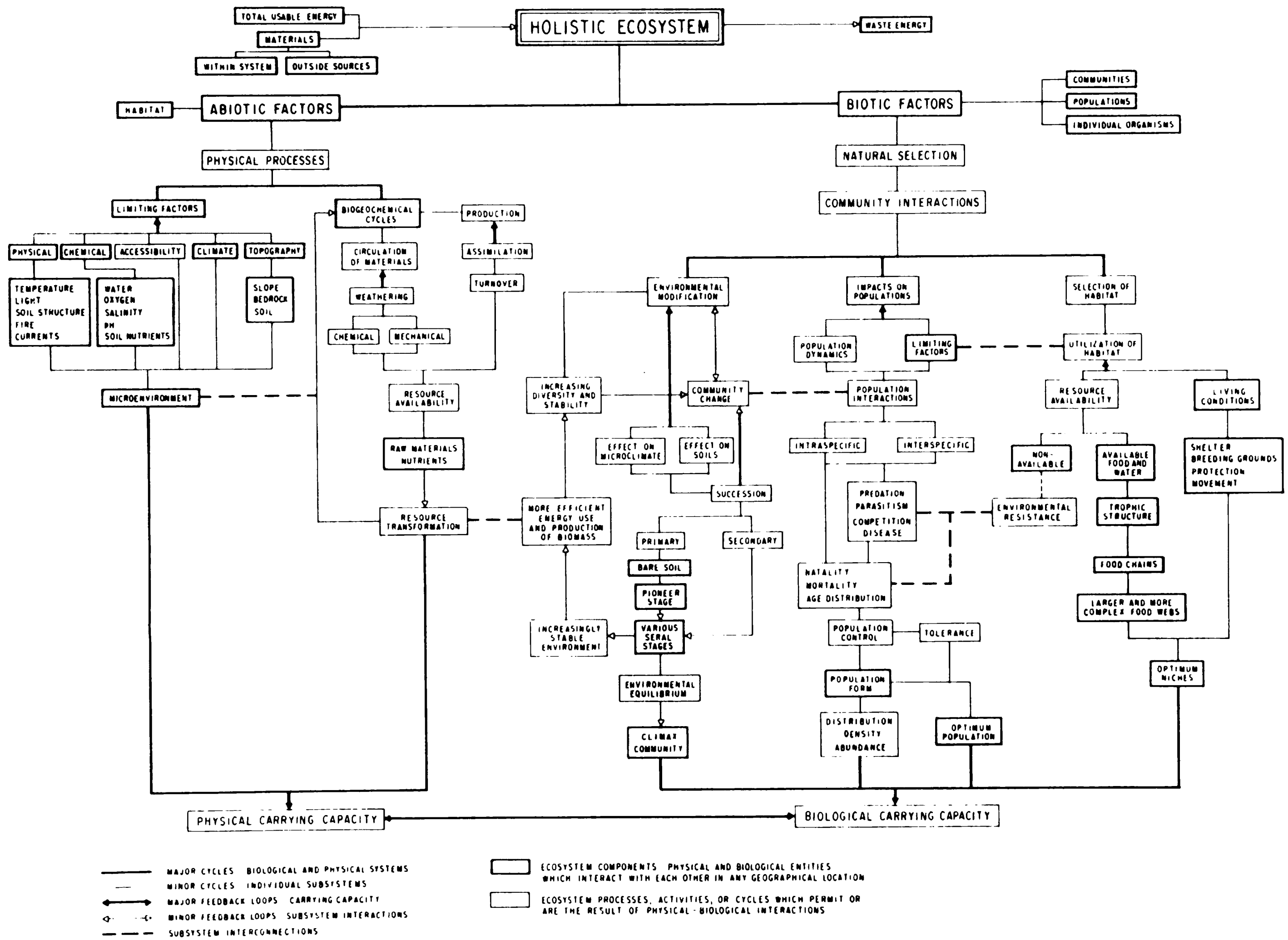

FIGURE 12. CONCEPTUAL MODEL OF A COMPLETE ECOSYSTEM.

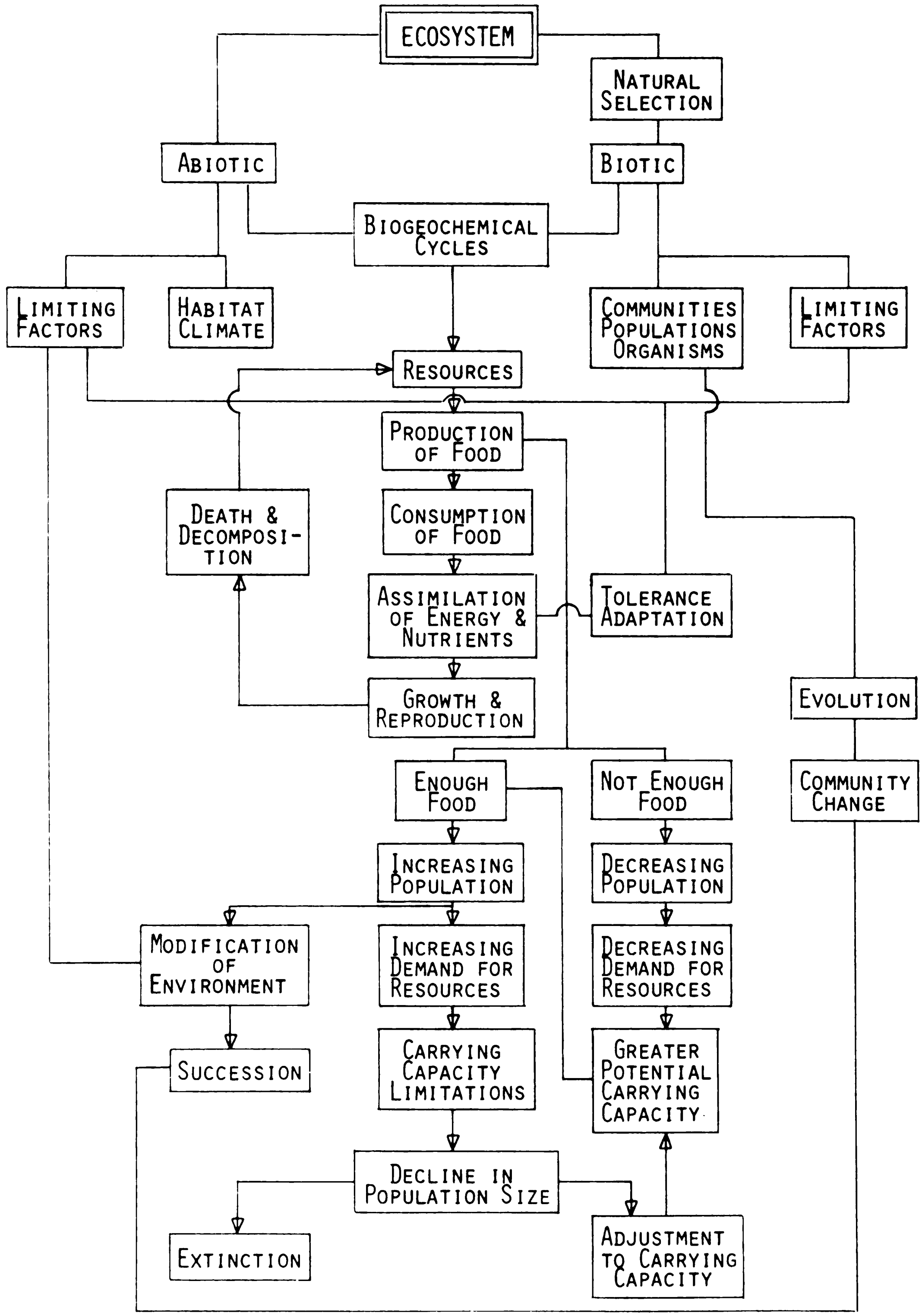

FIGURE 13. AN EXPANDED MODEL FOR ECOSYSTEM MANIPULATION - RELATIONSHIPS BETWEEN RESOURCE AVAILABILITY AND POPULATION DYNAMICS.

a series of hierarchical interactions between subsystems of the abiotic and biotic portions of an ecosystem. Physical or abiotic subsystems include limiting factors and biogeochemical cycles, while biotic subsystems include environmental modification, impacts on populations, and selection of habitat. Interactions within the physical sector determine physical carrying capacity; likewise, biotic interactions determine biological carrying capacity. Carrying capacity, because of its overall importance in establishing and maintaining the ability of an environment to support a given population of organisms is, therefore, used as a major connector between physical and biological components of the model. Connections are also provided between the individual subsystems to illustrate the close interrelationships found in all ecosystems. The flow nature of subsystem activities, such as community succession, are illustrated by minor cycles within subsystems; the cyclic nature of subsystem activities over a relatively long period of time are provided by minor feedback loops.

The purpose of developing a generalized ecosystem model is twofold. First, such a model can provide a basic review of the major components of ecosystems and how they are organized and interconnected. Second, a person studying or manipulating any ecosystem will have the ability to enter the system at any point, visualize the processes affecting that position, and predict possible effects that manipulation of that position would have on subsequent positions. By judiciously selecting entry points, an ecosystem manager can maximize the effects of manipulation while minimizing adverse impacts. Figure 13 is an illustration of this procedure. By examining the relationships between resource availability and population dynamics, a separate model can be constructed to demonstrate the feedback effect of carrying capacity on the success of a population in a given area. It can be seen that the availability of food is dependent on the size and growth of a population of organisms. If the population exceeds carrying capacity, it either adjusts its growth rate or becomes extinct. Associated processes such as community change and environmental modification are also affected by the flow diagram of food-population as shown in the model.

Conclusion: Understanding Ecosystems

A formulation and thorough understanding of ecological principles is essential to all people, whether they function as ecosystem managers or not. All of us are an integral part of natural and artificial ecosystems and therefore are governed by the same principles which control where and how a tree grows or why a fox preys upon a rabbit. Ignorance (intentional or otherwise) of ecological principles leads to several unfortunate occurrences:

(1) It causes and intensifies ecological degradation and destruction;

(2) It prevents us from understanding natural ecosystems and their intrinsic value; and

(3) It limits our ability to design human systems which are compatible with the environment.

The procedure which has been followed in the study of ecology begins with adherence to the scientific method of observation, hypothesis, and experimentation. This allows the systematization of ecological components and their interconnections and the ultimate formulation of predictive models. The accuracy and effectiveness of such models in the study, manipulation and, when necessary, preservation of ecosystems depends on the use of ecological principles in the model-building process.

In conclusion, a reiteration of general ecological principles may be helpful:

(1) POPULATIONS:

All living things are part of the physical system. Their density, abundance, development, and form are dependent upon biotic potential, environmental resistance, and the availability of ecological resources which are functions of the carrying capacity. Each species has a specific role (its niche) to play in the environment; eliminating a niche will eliminate the organism. Individuals of a particular species are present in any ecosystem due to dispersal, behavior, impacts from other species, and the combination of physical and chemical factors (Krebs, 1972).

(2) AVAILABLE RESOURCES:

Because of the laws of thermodynamics, energy flows through an ecosystem in only one direction and only by way of decreasing utility. Matter, on the other hand, cycles through the system and can be reused by living things. This is limited by the efficiency of the trophic structure and biogeochemical cycles.

(3) CARRYING CAPACITY:

The habitat provides organisms with their basic requirements for survival; the amount and availability of such resources determine the carrying capacity. Overuse of the habitat by populations of organisms lowers the potential carrying capacity which, in turn, limits the ability of the habitat to support a maximum and quality population.

(4) SUCCESSION AND STABILITY:

Communities change and evolve over time through the responses of organisms to the physical environment and to each other. Organisms which are better able to adapt to changing conditions eventually succeed each other by optimizing their niches as such niches change. This tends to increase the diversity of living things in a community and, in many cases, also increases the stability of such systems. All ecosystems are in varying stages of stability or dynamic equilibrium with their physical environment.

(5) SYSTEMATIC HOLISM:

Everything tends to affect everything else. Ecosystems have the ability to perform a certain amount of self-regulation within limits; if the limits are exceeded (as when a toxic substance is introduced), a species may be eliminated. If any other physical or biological factor is grossly disturbed, an ecosystem may no longer be able to function and may experience various patterns of change, injury, or breakdown (Southwick, 1976).

Because of their activities, needs, and wants, human beings are an integral and essential part of all ecosystems. Up to this point, however, human-designed and influenced ecosystems have not been examined in this paper because of the necessity to outline basic ecosystem concepts and fundamentals. The next chapter, titled "Land Use: Human

Occupance of Ecosystems," re-places humans into ecosystems by describing the uses, modifications, and impacts of people upon ecosystems.

CHAPTER FOUR

LAND USE: HUMAN OCCUPANCE OF ECOSYSTEMS

Introduction: Why Study Ecology and Ecosystem Theory?

The major premise of Chapters Two and Three is that ecosystems represent the basic units for studying and understanding ecology. Chapter Two began with a description of ecosystem fundamentals from natural and systems science standpoints. The chapter introduced the concept of ecosystem, and defined it as an open system of living and nonliving things in any physical space, its interactions and interrelationships being closely bound together in a dynamic equilibrium. The flow of energy, cycling of materials, production and consumption of food, life and death, growth, reproduction, and evolution are all subsystems of each ecological system, or ecosystem. All ecosystems interact with each other to form the biosphere, which is the very limited region of the earth whose conditions permit the existence of life.

The myriad of food chains and food webs; population structure, density, and distribution; and all of the other interactions which take place between living organisms and their environment rely on the complicated and rather rigid ecological principles described in Chapter Three. Because interactions within ecosystems are generally cyclical as opposed to linear (with the exception of energy flow), ecologists look at ecosystems as dynamic, ever-changing entities and have hypothesized various principles by which ecosystems are governed. Single populations of organisms and groups of populations, called communities, are constantly growing and changing in response to their environment. At the same time, the environment is being modified by the living things within it. Carrying capacity, the availability of natural resources for growth and reproduction, and the succession of one community by another are closely dependent on physical aspects of the environment such as energy and nutrient availability, climatic state, and other limiting factors.

Ecologists, ecosystem managers, and environmental planners can study ecosystems and ecological principles and construct accurate, predictive models. Graphic, mathematical and computer models have been described and represent a wide range of ecological functions - from a single predator-prey relationship to the complex input-output studies of large ecosystems.

Despite our efforts to the contrary, human beings are an integral part of ecosystems. Each natural ecosystem varies with the amount of human interaction and, it may be argued, no ecosystem on earth has escaped the human touch. From the human use standpoint, the study and understanding of ecosystems is important both intrinsically and practically. By its very nature, the ecosystem is the physical level at which living things and their interactions with each other and with the nonliving environment can best be observed and comprehended. The systems view provides a perspective for viewing man and nature and of organizing research and planning efforts in reference to the concept of systems and their properties and relationships. It is in the attempt to simplify the complex interrelationships that the ecosystem concept is most meaningful (Laszlo, 1972). In order for human systems to properly interact with natural systems, the complexities of ecosystems must be known to such an extent that the impacts of human activities may be predicted and, if necessary, mitigated.

The practical importance of understanding ecosystems is in directing the planning and management of human activities which use and transform ecosystems and their components. The ecosystem ultimately provides natural resources which must be properly managed to provide sufficient and long-term benefits. Planning land uses determines how and at what rate ecosystem resources are extracted, modified, conserved, or preserved. Energy, materials, food, living space, recreation, and even employment opportunities are provided, in part, by ecosystem management. The ecosystem, therefore, is the bridge between ecological theory and land use planning. Understanding and applying ecological principles to our uses of land and land resources ensures ecologically based land use planning.

Classification of Human Ecosystems

A continuum exists between the purest form of natural environment, usually pictured as a wilderness completely untouched by human influence, and the purest form of cultural environment: a large urban center which is completely artificial or man-made (Farness, 1979). The vast array of human land uses exists between the two extremes, each type of land use having a distinctive and proportional mix of natural and artificial components, values, and meanings. The continuum of land uses can be interpreted as a method of classifying human ecosystems. The mix of natural and cultural components determines the degree of human presence and utility of each system. Because current economic structures and technological capabilities have given humans both the desire and means to shape any natural system to fit the required ends, there is no ecosystem on earth which cannot be potentially altered. Therefore, the human presence in natural ecosystems is a factor which must be considered in any classification system regardless of geographical location or apparent lack of human presence. To illustrate this continuum of human ecosystems, a list is provided below which briefly describes various benchmarks along the continuum. This list includes:

(1) Pure Cultural Systems - such as the inner city which is an almost totally artificial combination of subsystems; natural components have been completely transformed to fit human needs and have to be imported into the city from outside; the only direct natural influences are from climate;

(2) Suburban Systems - primarily human artifacts with natural components, such as vegetation and animal life, modified for aesthetic fitness to the human environment;

(3) Exurban Systems - the mix of human and natural components are still heavily weighted toward the cultural environment although more natural areas are desired, such as city parks, greenbelts, larger estates or former farms which are primarily open space;

(4) Agribusiness Systems - this system has less direct human participation except for massive influences of technology; however, it is more dependent on natural inputs and constraints than previous systems;

(5) Subsistence Agricultural Systems - small, family-owned and operated farms which have not been modified greatly by inputs of technology and which produce food and fiber for personal

use; a wide range of uses is included in this category including slash-and-burn in forest ecosystems, terraced hillsides, and organic farming;

(6) Parks and Natural Areas - these systems are among the first along the continuum to recognize the importance of providing humans with opportunities for direct association with natural ecosystems, although such interaction is usually controlled and not mandatory (i.e., humans within these systems are only partially dependent on the nonhuman aspects - no one is forced to live in that environment);

(7) Natural Preserve Systems - areas either set aside because of their intrinsic values (limited-access sanctuaries) or their economic value to other human systems (hunting or fishing preserves); human use of such systems is limited and most natural processes are only slightly modified by human management;

(8) Pure Natural Systems (so-called wilderness areas) - there is some question as to whether purely natural systems which have never (or rarely) felt human influence exist; however, human activities are extremely limited and generally dependent on natural laws and principles - few humans could interact with such systems without large amounts of artificial support mechanisms.

While the preceding list is far from complete due to the other forms of land use, one can easily see how the varying mix of natural and cultural features can provide clues as to how each human ecosystem is structured and how it interacts with its environment. Other forms of land use (such as extraction of natural resources, transportation facilities, water resource use, and so on) can be placed along the continuum once its natural-cultural mix is known. Identifying the land use identifies the ecosystem (e.g., agriculture, urban, transportation, mineral extraction, farm woodlot, etc.), and it is at the ecosystem level that each land use is most adequately comprehended. The energy and material needs, productivity, the mix or diversity of living things, population and community dynamics, carrying capacity, and system stability can all be quantified and understood by considering each land use as a distinct natural and cultural combination.

This philosophy is in direct contrast to the more traditional classifications of ecosystems which generally presented such systems as biome-types or ecoclines described by various ecologists (Whittaker, 1975; Odum, 1959, 1971; Krebs, 1972; MacArthur, 1972; and many others). From an ecological point of view, the traditional classification is useful in describing each natural system, whether that system is a tundra, tropical rainforest, taiga, or steppe. Important components used to define each system include climate, soils, dominant vegetation and animal life, and successional stage (usually the climax stage for simplicity). Adding man to the picture tends to complicate things and, until recently, human interactions with natural ecosystems were literally ignored by ecologists. The second edition of Odum's Fundamentals of Ecology (1959) was one of the initial efforts to reverse this trend by the inclusion of chapters on man in natural ecosystems. The authors of more recent texts have also begun to realize this need, if only to report examples of human perturbation of natural systems.

On the other side of the spectrum are the multitude of environmental texts which tend to classify ecosystems from a land use impact orientation. Whether it is agriculture, urbanization, forestry, or recreation (to name a few), each land use is defined in human terms with little reference to natural or ecological principles. For example, carrying capacity is described according to socio-economic measurements in which a land area or resource can support only a limited quantity of people for a finite period of time (Gotschalk, 1974, 1975; and others). Human carrying capacity is only one form of carrying capacity which must be understood in order to classify each individual ecosystem. In essence, environmental texts classify ecosystems largely from a human use and perturbation orientation and tend to devote only a small portion (perhaps as little as a single chapter) to a description of ecosystems from an ecological standpoint. Because of this shortcoming, such classifications are just the opposite of disciplinarian ecology texts. Each group tends to criticize the other for failing to properly list all aspects needed to understand an ecosystem. Ecologists leave out the human component and write their texts in ecological jargon with little real-world applicability, while environmentalists fail to adequately describe natural components of ecosystems and tend to deal in the negative aspects of man-nature interactions.

The next two sections of this chapter examine (1) human interactions within ecosystems from an historical standpoint and (2) the impacts of such uses on various natural parameters. Since various authors have contributed well-written publications describing the impacts of humans on ecosystems (Dasmann, 1975; Foin, 1976; Sutton and Harmon, 1973; and others), the sections are intended to review and reinforce the need to classify and study ecosystems by considering their natural and their cultural components.

Human Use of Ecosystems: An Historical Perspective

Excellent histories of human interactions with natural ecosystems have been described by Miller (1975), Dasmann (op. cit., 1976), Bennett (1973), Southwick (1976), and Rodgers and Kerstetter (1974). There are three basic forms of man-nature interactions in history, and all three - man in nature, man versus nature, and man and nature - coexist even today (Miller, op. cit.).

The first of these, "man in nature," represents individuals and their societies as integral parts of natural ecosystems. In other words, primitive humans were completely dependent on the environment for survival. Early and advanced hunter-gatherer societies had to obtain food, shelter, and other needs directly from plants, animals, or nonliving substances occurring naturally in the ecosystem in which they lived. Until the widespread use of fire and the technological advances of tool-making, humans were completely vulnerable to the environmental constraints of carrying capacity and environmental resistance.

Early populations of humans were little different from populations of any other organism: they could increase their numbers only if there were sufficient quantities of food or a lack of competitors for resources. Humans learned which animals were capable of being captured and which plants could be eaten without ill effects. Humans also had to find shelter from adverse climatic effects and predators. These early populations maintained stability through high infant mortality and short lifespans, and it must be realized that the human species represented a single component contributing to the dynamic equilibrium of the total ecosystem.

"Man versus nature" represents the activities of human groups which influenced, transformed, or subjugated natural systems for their own use and benefit. In reality, this is what land use is all about. Humans have practiced land use from the simplest slash-and-burn agrarian systems to the most complex transformations of energy and matter of modern technologies. From the time man first used a stick tool to dig a hole for the planting of a tuber or seed, he has been a modifier of natural systems. His crops were vulnerable to changes in weather, soil impoverishment and erosion, or depradations from other organisms which were naturally occurring results of environmental modification. He has had to continually and increasingly add inputs of energy and technology to his efforts to overcome ecological constraints.

Early nomadic grazing and shifting agricultural practices resembled hunter-gatherer systems in that they followed the available resources and seasons. However, once areas that could support year-round activity were found, people tended to cease their movements and form settlements. Fewer individuals were needed to work the fields and tend the herds and, with increasing technology, crop surpluses were obtained to support a population removed from the land. This led to more specialization, class distinction and, unfortunately, social and environmental dysfunction. Warfare, slavery, overcrowding, disease, famine, and, ultimately, resource depletion and environmental degradation occurred. Poor or ignorant land use practices contributed to the decline and downfall of many civilizations throughout history (Dasmann, op. cit.).

The most serious manifestations of man versus nature would have to date from the beginnings of the Industrial Revolution to the present. In the last 200 years, cultural and natural resources that fit the industrial-technological institution were used in increasing amounts. More production meant larger populations of consumers who demanded more land and more land resources. Such "progress" was almost always at the expense of the natural environment: land grab, pollution and degradation of the commons, resource depletion, more land clearing for food production, extinction of species, and even extermination of societies still in a "man in nature" form of existence. The cultural environment was also being transformed concurrently with natural systems. Industrialized nations, in their thirst for new sources of energy and materials, subjugated large portions of the earth to fill their needs at the expense of other people who were less technologically advanced. As the grip of colonialism was released, the less developed countries sought to raise their standard of living to reflect the standard of living enjoyed in advanced nations. These people, representing the majority of the world's population, are just beginning to make their demands felt. The next section of this chapter, "Human Impact on Ecosystems," will examine the effects of land use patterns represented by "man versus nature" in greater detail.

The adoption of the ecosystem concept is necessary to implement a shift from "man versus nature" to "man and nature," in which human activities are planned and carried out to best fit the requirements of each ecosystem type. Mutual cooperation of all people working under ecological constraints is the only way to ensure survival of all forms of life - including humans. In order for it to function properly, any natural system is constantly striving toward equilibrium with its environment and toward stability in which production roughly equals consumption; the factors causing population increases are balanced by those favoring population decrease; and living things grow, reproduce, and die within the natural limits of carrying capacity. "Man and nature" requires the same type of equilibrium between human uses of ecosystems and the basic governing forces found in nature. Human conflicts, aggression, resource exploitation, and overpopulation must be overcome, based on an understanding of the relationships between living things and their environment.

In summation, this section has been a description of the continuum of time and cultural meanings and values of human land use patterns. Historically, human social groups have gone from being a relatively small part of natural ecosystems to attaining the ability to control and alter those same systems through massive inputs of energy and material transformation. To advocate a return to simpler, nontechnological lifestyles would be both foolish and unrealistic. While some isolated social groups such as communes have successfully adopted a simpler lifestyle, the majority of humans lack the ability to readjust, and intensive use of agricultural ecosystems will remain necessary to feed the growing populations. Instead, it is recommended that we continue to develop an evolutionary path away from centralized control and exploitation of natural systems to a healthy coexistence with those systems.

Human Impact on Ecosystems

This section addresses environmental and land use problems at the ecosystem level by examining past and present land use practices in relation to their ecological impacts. In order to understand man's place within ecosystems, it is necessary to examine how he has interacted with ecosystem components and ecological principles. Throughout their evolution, humans have increased their ability to manipulate, modify, and alter natural ecosystems. During the last 200 years, however, this ability has caused the most widespread and damaging changes. Most ecosystem alteration has been accomplished for the benefit of human populations and, while not all changes have been at the expense of natural ecosystems, it is unfortunate that the majority of them have.

Land use practices generally affect ecosystems by altering the diversity and stability of natural plant and animal communities, the quality and quantity of surface and subsurface waters, soil fertility and utility, presence and configuration of land forms or topography, and air quality (Bennett, op. cit.). Each of these areas will be examined in greater detail from an ecological standpoint.

Vegetation

Since the advent of agricultural practices, natural vegetation has largely been viewed as an obstruction to human needs. Generally, any plant that was not edible or otherwise economically valuable was replaced by species that were. Natural patterns of vegetation have been altered by fire as in slash-and-burn subsistence farming, removed by logging (and not reforested), modified by plow agriculture and selective grazing, and used for fuel. For example, it is difficult to find unaltered prairie vegetation in the American Midwest since the introduction of cattle grazing and farming in the last 100 years. This manipulation has led to an artificial selection in which man has selected against the original grass types in favor of corn or wheat crops.

Modern agricultural practices rely on maintaining plant communities in an early successional stage characterized by high productivity, rapidly growing populations, and lower species diversity. Unfortunately, this also leads to less stability and specialization in communities and populations, making the crops vulnerable to sudden ecological changes caused by the climate or insect pests. This, in turn, requires proportionately greater economic and technological inputs to maintain the necessary productivity required to grow the crops.

The introduction of exotic plant species has also led to various problems with internal ecological checks and balances. Introduced species such as tropical fruits and ornamentals have proven to be failures when they could not adapt to new conditions. Generally, however, introduced plants have become too successful. Due to lack of natural enemies or better adaptability, exotic plants have been able to outcompete with natural vegetation as any gardener would know.

Animal Life

As methods for hunting and domesticating wild animals became more efficient, humans were able to widen their mastery over larger numbers of species and also choose those species of value. "Good" species were either domesticated and bred for species enhancement (artificial selection) or they were managed in the wild for food or pleasure. "Bad" species were designated as such because they directly competed with humans for food (or made humans part of their diet). Attempts to eradicate these competing or dangerous "bad" species remain in practice. The use of chemical pesticides has increased to serve this end. Because of biomagnification through the food chain, the cumulative effects of chemicals may not be ascertained for many years.

Major impacts on wildlife have occurred through market hunting, habitat destruction, and the introduction of exotic species. Commercial hunting practices have caused the extinction of numerous species (passenger pigeon, dodo, great auk, heath hen, etc.) and the widespread disappearance of others (the great whales, wolves, birds of prey, etc.). Habitat destruction has had, and will continue to have, the greatest impact on distribution and abundance of animal species. Reducing the amount and quality of native habitats directly affects the carrying capacity of each ecosystem to maintain an animal population. The disappearance of the ivory-billed woodpecker is a good example of the negative aspects of habitat destruction. The introduction of exotic species presents the same problems to animal populations as it did to plants: exotic species may carry diseases to which native populations have no natural resistance; they may be able to outcompete native species (as in the starling, house sparrow, and Norway rat) or they may lack natural enemies and become economic pests (e.g., the Japanese beetle, European corn borer, or Dutch elm disease).

Surface and Subsurface Waters

Water resources have been engineered - and polluted - to meet human needs. Because water is so essential to life, its presence or absence from an area is a determining factor in carrying capacity.

Therefore, water supplies have been dammed, canalled, diverted, and pumped from areas with surplus water to those lacking it. Impoundments and diversions have resulted in the loss of wild, free-flowing rivers while the quality of the water itself has usually decreased as a result of such manipulation. Flowing water has a higher concentration of oxygen and is generally cooler than still water, while the sediments carried by flowing water tend to settle out when the velocity is decreased. This has led to changes in plant and animal succession, diversity, and density; lowering the water quality; and causing engineering problems such as siltation.

Areas without surface water sources have had to rely on pumping underground water. As long as recharge was adequate, long-term availability was not seriously altered. However, increasing demands have lowered water tables to the extent that underground water (in reality, a nonrenewable resource) is now being mined in many areas. Other problems associated with pumping subsurface water have included land subsidence and salt water intrusion.

Water sources have also been used as sinks for human, industrial, and agricultural wastes. Clean, flowing water has the natural ability to assimilate organic wastes through oxidation and trophic utilization. However, large amounts of sewage, toxic substances, fertilizers, and heated water seriously reduce the capacity of natural waters to purify themselves. In natural ecosystems, this results in early eutrophication (succession); changes of species diversity, carrying capacity, distribution, abundance, and even the presence of organisms; and decrease in usability for future human needs.

Soil Fertility and Utility

Poor land use practices and ignorance have led to soil erosion and impoverishment. Soil erosion results from stripping the natural vegetation from the land through fire, logging, agricultural practices, or overgrazing and neglecting to replace the natural vegetation with other plants (as in clearcutting) or planting new species which inadequately anchor the soil. The exposed soil is subject to natural weathering by wind and water until the most fertile upper horizons are no longer available for either natural or human use. Examples of widespread soil erosion have occurred in the Dust Bowl of the Great Plains and in the desertification in northern Africa. On the other hand, irrigation projects in arid regions and good soil conservation practices have resulted in maintaining both soil fertility and quantity for long periods of time.

Soil impoverishment has resulted from a combination of human practices (changes due to massive applications of pesticides and fertilizers) and natural causes (nutrient leaching in tropical lateritic soils cleared for agriculture). Inputs of artificial substances to enhance crop growth may also kill soil microorganisms which, if left alone, act as soil builders by decomposing organic material. The buildup of chemicals may become toxic to larger forms of life, including man.

Landforms

Man has been altering the surface configuration of the earth in varying degrees since he began extracting minerals from the earth and building temples to his gods. When human numbers and needs were relatively few, natural landforms presented limitations to movement, resource procurement, and settlement patterns. Today, a mountain in the way is moved, a flooding stream is dammed, or a valuable resource is mined after removing hundreds of feet of overburden.

Mining (whether open pit, placer, hardrock, or strip) and land sculpting (for roads, railroads, streets or building sites) are feasible in nearly any environment due to advanced technological tools and the economic incentives for their application. However, in the process of topographical alteration, the physical components of ecosystems are also altered, directly impacting the living organisms associated with and dependent on them. After a mineral is extracted, hardrock spoils from mining operations present an extremely hostile environment to plant and animal recolonization. Sealed surfaces from buildings or pavement take the soil out of production (for natural as well as human use) and prevent natural percolation of water into ground strata. Loss of habitat has already been mentioned as a detrimental impact which directly affects natural ecosystems.

Atmosphere and Air Quality

Human impacts on the atmosphere are perhaps the least understood aspects of human interactions within ecosystems. It is relatively well-known what types of activities are causing what forms of air pollution, but the long-term effects on both human and natural systems are less clear. The major source of air pollution (excluding volcanoes) is from the burning of fossil fuels for transportation and power generation. The proportions of gaseous materials and particulates from combustion are well-known, although potential toxicity of such materials on living things is still being studied.

Potentially damaging substances include oxides of carbon, nitrogen, and sulfur; ozone; fly ash; soot; and heavy metals such as lead, cadmium, and zinc. Most of these substances occur naturally within the matter cycles and can be assimilated in small amounts by living things. However, large portions can kill organisms and cause environmental modification and succession to certain species that are less desirable to most humans.

Other atmospheric impacts include radioactivity from nuclear weapons testing and climatic alteration from weather modification intentional and incidental to other land uses. Long-term impacts from radiation may include environmental diseases such as cancer or even an acceleration of natural selection due to increased mutation. Affecting the weather may increase desirable weather patterns in one region at the expense of other areas. For example, enhancing rainfall to one agricultural region may "dry up" some regions and cause disastrous floods in others. Impacts on local climates have resulted from large water impoundments, airports, and cities.

A debate is currently raging concerning the long-term effects of particulates in the atmosphere, particularly carbon dioxide. The presence of microscopic particles affect the amount of solar reflectivity - if more of the sun's rays are reflected back into space, the overall climate of the earth may cool, possibly triggering a new ice age. On the other hand, a dense particulate canopy may act as a layer of insulation preventing heat from escaping the earth. A resultant rise in temperature may induce melting of the polar ice caps and subsequent submergence of the major population centers.

principles contribute to achieving a mature balance between natural and cultural systems because they form the basis for developing dynamic land use policies and management techniques in addition to traditional economic, political, and technological inputs.

The next two chapters will first look at ecosystem planning and then at management with the intention of (1) limiting negative human interactions with the environment, and (2) developing a methodology which will promote the man-and-nature perspective introduced in this chapter. Any one of the preceding problems, whether it is land, air, or water degradation; loss of plant or animal species; or a reduction in resource quality, if unchecked, may result in seriously limiting the ability of the environment to support human populations at even the subsistence level. It is therefore necessary to observe, study, plan, and manage the environment with the philosophy that such use must be ecologically sound.

Use of the ecosystem concept, introduced and developed in Chapters Two and Three and adapted to a human land use orientation in this chapter, will become the focus in developing a planning and management methodology in the next two chapters.

CHAPTER FIVE

PLANNING FOR THE RENEWAL AND MAINTENANCE OF ECOSYSTEMS

Problem Definition

A plan is a proposed method of achieving a desired end. While there are various forms of planning strategies, certain functions seem common to most plans. Plans are usually goal-oriented; i.e., problems are identified and a systematic procedure is required for their solution; and they are administrative tools. Data must be gathered and integrated into a meaningful and usable form; an official document is produced which usually lists and examines alternative solutions before choosing the most appropriate one; and the plan is implemented and administered according to its particular application. In addition, a plan and the planning process must be somewhat flexible to accommodate new information or needs, and the duration of its effect must be long enough to justify the expenses incurred.

Since planning is problem-oriented and goal-directed, it is necessary to examine how planning fits within an ecological perspective and vice versa. Poor planning with respect to the environment and its various ecosystems has led to such overwhelming problems that only a total reorientation of current planning efforts will remedy the situation. Pollution, resource depletion, the extinction of various organisms, and human overpopulation are notable examples of poor planning. Obviously, the goal of ecologically based planning is to reverse the above trends and establish a better quality of life. Renewal and maintenance of ecosystems regardless of their present state of quality is also a basic goal because all humans depend on the functioning of ecosystems for their survival.

This leads to another problem which must be addressed in the planning effort: bridging the gap between ecological theory and land use planning. There are natural ecosystems and somewhat less-natural human ecosystems. It should be the intention of planners, resource managers, educators, and so on, to study and understand natural ecosystems so that the evolution and design of human ecosystems can imitate the functioning, efficiency, and fitness of more natural ones. Planners and managers who make decisions - answering the questions of how, where, and in what quantities natural and human resources are used - must apply ecological principles and accommodate ecological constraints to ensure that environmental decision makers deal with living and nonliving resources. An understanding of the structure and function of ecosystem components, their interactions, and the collective "whole" is also necessary. This understanding requires a careful selection and combination of elements from various sources of information which form the set of practices and idea systems needed to plan and manage ecosystems and the resources they provide.

While it is important to indicate that ecologically based planning is necessary from the standpoint that, for the most part, such efforts have been inadequate or totally lacking, it is also necessary to define those areas and select decision makers that should be part of the process. Appropriate planning functions include the renewal and maintenance of ecosystems in virgin lands, recently exploited lands, and lands which have been used on a long-term basis. To be truly inclusive, the list should contain aquatic ecosystems as well, particularly in oceanic and estuarine areas which have been projected as necessary for providing food to a starving world. Obviously, every land and water area on the earth will be included at one time or another. The utilization of any land area or land resource (for purposes of simplification, the inclusion of aquatic ecosystems will be assumed) requires an understanding of that resource, how that resource is connected with other ecosystem components, and the long-term consequences of such use. For example, a decision to develop a new energy-using technology may require an intensive search for future energy supplies. If it is found that adequate supplies are present in a previously protected area, pressure to extract that resource will increase, and the functioning ecosystem in the area will be affected. This is a value judgment which might have more far-reaching ramifications than the resource planners originally thought. Rare species might become endangered ones. In addition, certain biophysical processes which are vital to human well-being (such as air or water purification, the amelioration of toxic substances, or the production of future foods or medicines) could also be threatened. The list of ecosystems which require renewal and maintenance includes intensively used land areas such as prime agricultural and other food- and fiber-producing areas. Constant use of biocidal and fertilizing chemicals, the elimination of natural checks and balances (such as beneficial insects), and urbanization may seriously affect the long-term productivity and availability of such important areas.

The list of people who should plan their activities around ecological principles includes everyone - from the suburbanite who waters, fertilizes, and mows his lawn to the chairman of a multinational energy-producing corporation. In other words, everyone's life depends upon transformed ecosystem components (resources) and the ecosystems from which they come. The efficient and optimal extraction and use of such resources depends on properly orienting the planning function, not only to provide economic and social goods, but to protect and enhance the biophysical support functions which allow the continued provision of such goods. Poor planning may cause environmental disasters and enormous costs to correct the situation.

There are three general classes of resources which require the input of ecological information to enhance their manipulation and use. These classes include (1) nonrenewable resources, and (2) renewable resources - the so-called fund and flow resources - and (3) other land areas which could be designated for either of the above uses but, because they are used for living space or wildlife refuges (for example), are not (Barlowe, 1972). A planner, such as a coal-mining engineer, is dealing with a nonrenewable resource, and is concerned with the most efficient, safe, and cost-effective extraction of coal from a surface mine. His planning efforts should also include sufficient information to minimize environmental disturbance and pollution. He must be able to plan the proper reclamation of the landscape after the coal has been mined. His resource use affects local ecological conditions and may, through runoff and machinery exhaust, have some farther-reaching consequences in more distant parts of those ecosystems as well.

Planners of renewable resources, such as farmers and foresters, must be aware of the potential impacts of the chemicals (such as pesticides and fertilizers) used in their operations and also in any land-clearing activities. Research and careful planning are needed to assess the impacts which may affect the proper functioning and interactions of physical (air, water, soils) and biological (plants, animals, and humans) components of local ecosystems. The all-too-familiar case of high pesticide residues in Great Lakes salmon and lake trout exemplifies this very well. Through biological magnification within the food chain, relatively nonbiodegradable pesticides such as DDT and Dieldrin began to concentrate in the fatty tissues of such fish. Health officials expressed concern that such high levels might become toxic to the fish and to the people who ate them. Proper planning, development, and use of degradable pesticides of natural origin may have less long-term ecological impacts on components and functions of ecosystems which were not meant to be affected (Odum, 1975).

The final area of land use and resource planning includes those ecosystems which, although not designated for production as in the preceding cases, are suffering from increasing development pressures. Land areas experiencing rapid urbanization are often out of balance with both the cultural and natural ecosystems (Stearns and Montag, 1974). The flow of food and water and the provision of shelter (housing), safety, environmental quality, and aesthetically pleasing surroundings are interrupted in the process. Building on floodplains or recharge areas, siting power plants in geologically unstable areas, and conversion of functioning natural ecosystems to disrupted ones are only a few examples of planning efforts which have had disastrous results.

It is helpful to reiterate the goal orientation of ecologically based land use planning and how it assists in the planning effort. First, ecosystem planning is based on the fact that the ecosystem is the most suitable location for planning human interactions with the biophysical world. Second, ecosystem planning provides an understanding of components, structures, functions, and interconnections which no listing or inventory could approach. This understanding helps explain the natural constraints which govern all ecosystems from the simplest natural systems to complex, cultural (less natural) human ecosystems.

Finally, ecosystem planning allows a holistic, systems approach to human endeavors in which activities can be planned and properly implemented with a view toward the functioning and maintenance of the biosphere as a whole. Ecological problems can be sorted and classified according to their impacts on both human and natural systems, and solutions can be found and implemented with a philosophy of environmental fitness and appropriateness.

Information Base

Once problems have been identified and goals established, the next step in the planning process is implemented: gathering, organizing, and combining information into the formulation of a plan or course of action with regard to identifying and using resources, planning future developments, or addressing environmental problems. In the study of ecosystems, it is necessary to establish a meaningful information base. This is an important remedy to the problem of gathering copious amounts of data with the hope that everything necessary to properly plan ecosystems will somehow be obtained in the process. Holling and Clark (1975) speak of the need to establish a sound information system based on (1) the conceptual framework of ecological theory which explains ecosystem structure and function, (2) simplified simulation models and management programs which can be integrated to explain or solve environmental problems, and (3) extensive and intensive empirical studies which describe causal relationships.

The conceptual framework provided by ecological theory has been discussed in Chapters Two and Three of this paper while the solutions to environmental problems will be examined in the next chapter on ecosystem management. This section will describe the information systems necessary to inventory, describe, analyze, and classify ecosystems to provide a usable information base for ecosystem planning. Such an information system must be oriented according to an ecological classification (see below) and have both natural history and cultural information as major components.

Ecosystem Classification

The purpose of ecosystem classification is to provide a standardized and meaningful organization of all of the data gathered on ecosystem components, subsystems, structures, functions, and interactions which are necessary to plan and manage such systems. Such a classification will provide a common starting point for the interactions of ecologists, systems analysts, planners, managers, and other decision makers. The proposed method of ecosystem classification (described in Chapter Four) is based on an evaluation of (1) the spatial extent of a particular ecosystem in question (after it has been defined according to type -

usually vegetation, soils, and climate) and (2) the degree of naturalness, or the combination of relative amounts of cultural (man-made) and natural influences or components. This method is an integration of land use classification (in its many forms) and ecological classification, which is exemplified by several phytosociological or wildland classification schemes (Driscoll and Spencer, 1972; Corliss, et. al., 1973; Michigan Department of Natural Resources, 1975; Brady, et. al., 1979).

Defining the spatial or geographical dimension is one of the more difficult problems in ecosystem planning simply from the standpoint of setting meaningful boundaries. Discrete geographical entities such as watersheds or regions of homogeneous patterns of vegetation (biomes) have been suggested as possible foci of planning efforts. However, such large land areas usually cross political boundaries such as state or county lines, and jurisdictional disputes are often the result in large-scale regional planning. It may be necessary to begin with small-scale operations - neighborhoods, private lands, urban centers, parks, and so on - to gain the experience, confidence, and support to plan in regional ecosystems. Regardless of spatial extent, definable ecosystems will be present in any land area chosen for classification, study, or development.

Land use classifications are not new; many states began inventorying their agricultural and forest lands during the early 1900s (Barlowe, op. cit.). Such classification schemes were not based on natural land units; rather they were laid out according to the rectangular land surveys. Thus, political units such as counties delineated the spatial orientation for such natural classifications (soils) as those developed by the U.S. Soil Conservation Service. Other countries, such as Canada, Australia, and Mexico, have improved this resource classification scheme by carefully describing the interactions of soils, hydrology, landforms, and climate as components of a production function. The Food and Agricultural Organization of the United Nations has developed a system-based land evaluation for agricultural production which is being advocated for developing countries (FAO, 1976). However, such classification schemes still tend to be administered according to political rather than ecological boundaries.

Ecologically based classifications have largely originated in Western European countries (most notably in The Netherlands and Great Britain) and in Canada. In Canada, Angus Hills (1961, 1970, 1976) has proposed a total site classification which approaches an ecosystem classification; his system is based on a description of natural characteristics such as surface relief, geological materials, climate, and soils. His method is one of the first to look at natural systems holistically and attach ecological significance to the components used in the description. Hills' classification is directed at the evaluation of the capability, suitability, and feasibility of ecosystems for all types of biological production. The overall philosophy is to classify ecosystems according to their capability of producing living organisms of various kinds (and economic potential) under various combinations of circumstances. While it may be argued that all ecosystems should not be evaluated as production units, the fact that it is a knowledge of ecosystems and ecological theory which predicates the evaluation process sets an important precedent. In addition, Hills' methodology began to examine the interaction between natural and inherent land use capabilities and public welfare and institutional demands for land use controls. This examination of natural and human ecosystem development provides a foundation for more meaningful ecosystem classification.

Other Canadian attempts at land classification are also notable. Dansereau (1978) and Brady, et. al., (1979) have begun to classify ecosystems according to their cultural-natural mix as well as placing such methodologies within an ecological framework. Although both classification schemes are directed more toward urban ecosystems, the approach used can be very helpful in understanding environmental problems caused by the subjugation of natural systems by human activities and also the ecological cost of such activities normally viewed in social, political, and economic terms. Both approaches are recommended to provide background material in developing an ecosystem classification process.

The first pragmatic approach to ecosystem classification (as well as planning and management) has been proposed by Van der Maarel (1978). Since ecosystems provide a number of functions to human systems (and damage to those ecosystems results in a loss of function), ecosystems should be classified, renewed, and managed according to the interactions between human and natural environments. Functions include production of food and materials, regulation of waste products, scientific information, carrying capacity, etc., and overuse or overexploitation of such functions may cause total system breakdown. Van der Maarel recommends a classification using a set of indices which can be used to describe the state of the system and to establish baseline points for system renewal and management. The overall classification is based on degree of naturalness with indices (value descriptors) of scarcity, diversity, and structural diversification. Together, these indices can describe the state of the ecosystem to provide information for projections of what the system might do in case of an environmental impact from proposed plans or management activities.

The use of indices can be of value in guiding the information-gathering process because such natural functions are determinants of productivity, structure, and species composition of ecosystems. This is helpful in the determination of what information should be gathered in an ecological inventory. Basically, an inventory is taken to find out what is there and how much. This gives planners, resource developers, and managers not only an idea of the richness of the ecosystem from a biophysical standpoint, it also indicates the degree to which the system may respond to human activities and influences.

Ecological Inventories and Descriptors

The compiling of extensive and exhaustive lists, which has been done in past environmental impact assessments, is largely a waste of time and money, as are comprehensive "state of the system" surveys and detailed descriptive studies (Holling, 1978). The major benefit of including lists of species present or descriptions of physical conditions is to notify planners of potential constraints presented by an ecosystem. Obvious constraints to planning the use of ecosystems - rare or endangered species, areas of geological instability, unique ecological conditions, natural hazards, and so on - should be listed. It is recommended that, if a listing is necessary and required, the activity be done as cheaply and simply as possible using survey checklists such as those developed by the U.S. Environmental Protection Agency which indicate assessment parameters specific to particular resource or environmental problem areas (for example, water quality management (EPA, 1972)). Other, more extensive inventory systems may also be helpful, such as The Natural Resource Inventory Checklist developed for the National Science Foundation by the Montana Agricultural Experiment Station (1979). Such approaches can be modified to suit particular circumstances and planning constraints and need not be followed religiously.

Of greater importance than listing ecosystem components is the organization of those components according to their causal relationships: their structure and function, how they interact, and how they influence the processes which are essential to humans. In order to plan for ecosystem renewal and/or maintenance, these relationships must be intensively and extensively studied and then manipulated - but only after they are understood through simulation techniques. The measurement of ecological relationships is essential to establish a meaningful information system which can be useful to the land use planner. Following is a list of ecosystem components and conditions which should be measured, and a recommended method by which they can be measured:

(1) Productivity and biomass supported (bioenergetics) are measures of community dynamics and are quantified by establishing the ratios:

(a) P/K where P is gross production (amount of organic matter photosynthesized by the producers of the ecosystem) and K is community respiration (biomass lost through respiration or metabolism). (See Chapter Two.)

(b) P/B where P is gross production and B is standing crop biomass (the dry weight of living organisms). P can also be expressed as GBP or gross biomass productivity, thus yielding the fraction GBP/B. Likewise, NBP or net biomass productivity (measuring loss of biomass through respiration) gives a more meaningful interpretation of K in equation (a).

(c) B/E where B is biomass supported and E is unit energy flow (available energy for production within a defined area; Odum, 1969; pp. 262-270).

(d) Another measure of importance in bioenergetics is that of turnover time (the time needed for the ecosystem to produce an amount of biomass equal to that of the standing crop. It is the inverse of the equation in (b): T = B/GBP. Young and simple ecosystems (early successional states) tend to have shorter turnover times than ecosystems further along on the continuum toward climax (Brower and Zar, 1977; p. 149).

(2) Trophic relationships of species (or who connects with whom via energy and nutrient pathways) can be quantified by (a) predator-prey studies which list "species eaten" and "species eaten by" to produce an index of a particular organism's position within the food web (Tyler, 1975; p. 102), and (b) by the construction of a model food web with arrows showing major energy transfer pathways and diversity indices which give an indication of relative ecosystem stability (Brower and Zar, 1977; pp. 135, 136-142).

Figure 14 is an example of food web models constructed by an ecologist after field observation. Note that the simple model on the left is more susceptible to disruption than the relatively more complex model on the right. Such models are good indicators of ecosystems which must be carefully managed.

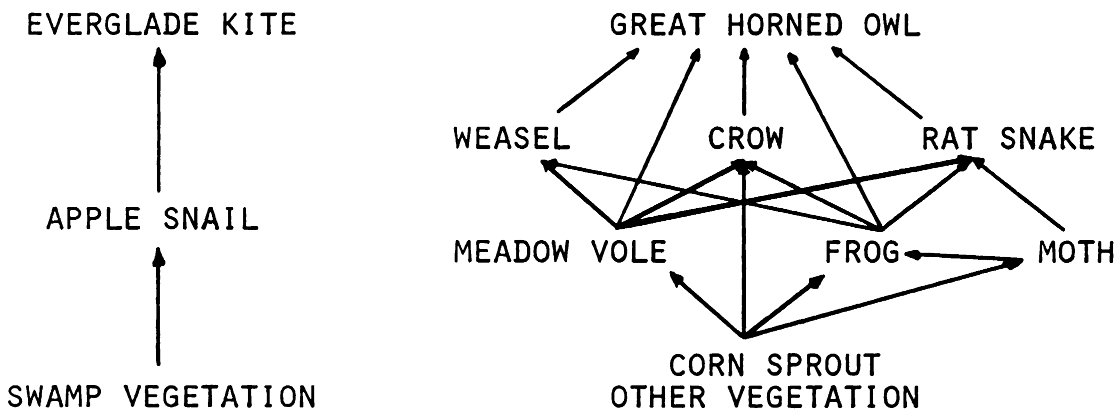

FIGURE 14. TWO EXAMPLES OF MODEL FOOD WEBS USED TO INTERPRET TROPHIC RELATIONSHIPS.

(3) <u>Scarcity, diversity (richness, number, and abundance of species), and variability</u> of organisms, landscapes, soils, etc., within a community or habitat can be measured according to a relative proportion of occurrence within a given geographical area (Odum, op. cit.; Van der Maarel, 1978; pp. 421-423, 435). Of the many measurements of species diversity, Brower and Zar (op. cit., pp. 136-140) recommend Simpson's Index (Simpson, 1949) and information-theoretic indices for use in ecological data collection. Simpson's Index considers number of species (s), total number of individuals (N), and the proportion of

the total that occurs in each species (n_i = relative abundance):

$$Ds = 1 - \frac{\Sigma\, n_i\, (n_i - 1)}{N\, (N - 1)}$$ where the species were randomly sampled.

Information-theoretic indices can calculate diversity of random samples according to abundance, habitat heterogeneity, diversity of biomass, and relative abundance or relative biomass. Nonrandom samples can also be used to predict species abundance:

Random: $H' = (N \log N - \Sigma\, n_i \log n_i)/N$ (log base e, 10)

Nonrandom: $H = (\log N! - \Sigma \log n_i!)/N$ (log base e, 10)

(4) <u>Structural differentiation and successional stages of communities</u> can be measured through stratification or life-form analyses based on indices of relative maturity of dominant species (usually vascular plants). Whittaker (1975; pp. 174-179) lists measurements of (a) productivity, (b) biomass, (c) biomass per annual net productivity (biomass accumulation ratio), and (d) growth in stock of inorganic nutrients as indicators of successional stage. Detailed observations are sometimes necessary to note changes in populations, increases in diversity, and shifts in dominances attributed to ecological succession.

Whittaker (op. cit.; p. 104) also utilizes vertical and horizontal gradients to demonstrate structural differentiation in ecosystems. Profile diagrams (measuring stratification) show different plant growth forms and indicate animal species at different levels (according to niche). Measurement of stems per hectare, moisture gradients, and soil types which create mosaics of species correlations (those that tend to occur together) are examples of horizontal gradients. Other workers, particularly Van der Maarel (op. cit.) have recommended measuring gradients of climate, hydrology, geomorphology, soil texture, soil chemistry, and animal or human influence to establish structural (or niche) differentiation.

(5) Spatial and temporal relationships of populations and communities are difficult to measure unless extensive observations are taken and compared with research results. However, gaining this information will provide insight into species' habitat requirements and the relative richness and health of habitats in question. This can be of value in scheduling management activities for the least amount of disturbance to natural processes. Measurements include:

(a) species movement - diurnal and seasonal, migration patterns, dispersion of population - can be measured by distribution of nests or burrows, bird banding, browse lines, radio telemetry, etc. (Avery, 1975; p. 223; Watt, 1968; pp. 252-352);

(b) population age and health can be determined by live-trapping and the analysis of habitat utilization; evaluation of population change over time can be based on the number of individuals gained or lost relative to the original population in an area or on changes in the predator-prey balance (Pianka, 1978; pp. 99-118; Odum, 1959; pp. 150-177; Watt, op. cit.; pp. 21-36, 189-224);

(c) habitat utilization is a measure of habitat quality, or the ability of a habitat to provide food and shelter for any particular species - in essence, an indication of carrying capacity (Pianka, op. cit.; pp. 238-251); habitat analysis procedures presented by Avery (op. cit.; pp. 220-235), Giles (1969), and Brower and Zar (op. cit.; pp. 27-33) will give a representation of available habitat resources and how they are being utilized by species present; it will also be useful in determining interspecific relationships in time and space (e.g., competition, niche utilization, etc.).

(6) Degree of naturalness has been discussed above and in Chapter Four. Classifying ecosystems according to their relative naturalness requires generally subjective measurements on the part of the observer. In addition, Van der Maarel (1975, pp. 265-266) lists a cross-matrix of measurement categories which can assist in determining degree of naturalness. These include:

(a) rate of influence of man on biotic components of an ecosystem (land use classification forming six categories: natural, near-natural, semi-natural, agricultural, near-cultural, and cultural);

(b) origin of ecosystem (four categories: natural, semi-natural, agricultural, and cultural); and

(c) present state of development or successional state (three categories: pioneer, development, and nature).

The preceding list was developed with an ecological orientation. It is recommended that such parameters be measured by a team of qualified ecologists who are aware of the constraints and implications of the proposed planning activities on natural components and functions. The measurements listed are by no means the only ones available for use by data collectors. There are several recommended texts on ecological measurement and sampling techniques, including Ecology and Field Biology (Smith, 1980; Appendix B, C) and Field and Laboratory Methods for General Ecology (Brower and Zar, 1977). The information collected can be used to establish a description and weighting of those biophysical supporting functions (listed below) which are essential to human ecosystems and may be affected by the planned activities (McHarg, 1969; p. 57):

(1) natural water purification;

(2) air pollution dispersal;

(3) climatic improvement and regulation;

(4) water storage;

(5) flood, drought, and erosion control;

(6) topsoil accumulation; and

(7) plant and animal inventory increase.

Because the proposed classification contains a mix of natural and human (cultural) ecosystem components and functions, it is necessary to provide inputs of ecosystem descriptors from the human as well as ecological standpoint. A description of the degree of naturalness would be the logical first step to which would be added an assessment of environmental quality and ecosystem richness. This method not only provides a description of land types, uses, and capabilities, it also allows the input of natural and human values and needs. Such values can be interpreted as philosophical, as well as economical (e.g., agriculture, forestry, or land values) and ecological (e.g., plant associations, wetlands, floodplains, or endangered species). The latter two values are obvious and well documented: there are definite benefits in maintaining system integrity by protecting ecological components and processes, and there are benefits in maintaining productive cultural entities such as farms, factories, and communities.

Value descriptions should also include determinations of past and present damages and dysfunctions along with some projection of what it may cost to replace the damaged areas. If natural functions (such as the cooling effect of a forest canopy) are destroyed, they must be replaced by expensive and energy-wasting tools (in this case, air conditioners). Listing philosophical values such as aesthetics (a beautiful and scenic view), tradition (protection of historical artifacts), existentialism (protecting a species for its own sake), symbolic (preserving a wilderness as an example of "nature in balance"), and enhancing the "perfect" community of "Man and Nature." Including values in the information-gathering process of describing lands and land uses helps establish perspectives for present and future interaction with and management of natural ecosystems.

Application of Environmental Information

Applying the information gathered for the solution of environmental problems and planning goals represents the analysis and assessment phase of an ecologically based planning methodology. This analysis and assessment phase requires a thorough and sometimes exhaustive organization of information to be meaningful in each decision-making situation. It is also in this phase of planning that ecological theory is applied co-equally with ideas and requirements of economics, politics, technology, and social institutions to plan truly balanced natural/cultural ecosystems. Not only is the integration of the various disciplines necessary from a decision-making standpoint, it is also necessary from the point of view of individual citizens - those who are most directly affected by any planning situation. Therefore, a plan must be acceptable as well as meaningful.

It is helpful from a conceptual and practical standpoint to identify certain phases of a plan where information should be applied. These areas, listed below, have been identified by McHarg, through his "ecological determinism" methodology used in <u>Design With Nature</u> (1969); by Holling's adaptive environmental assessment and management approach (1978); and by Andrews (1978), who has developed the following application framework consisting of three parts:

1. Identification of Constraints

Constraints confronting the planning and use of ecosystems can be both natural and institutional as shown in Figure 15. Such constraints present limiting factors which must be accounted for in feasibility studies, site planning, or in the development and application of land use controls. Natural constraints are based on natural laws and processes which, if ignored, may result in death or costly destruction, as in the cases of developments in geologically unstable or flood-prone areas, the irreversible extinction of flora or fauna, or the expensive

	HAZARD CONSTRAINTS	LEGAL CONSTRAINTS	SOCIAL OR PROFESSIONAL VALUES
NATURAL	UNSTABLE SLOPES EARTHQUAKE ZONES HURRICANE COASTS TORNADO BELTS FLOODPLAINS	ENDANGERED SPECIES SPECIAL ECOLOGICAL COMMUNITIES WILDLIFE REFUGES CRITICAL AREAS	URBAN OPEN SPACE WOODED AREAS WATER FEATURES PLEASING DESIGNS PRIME AGRICULTURAL LANDS
ARTIFICIAL	AIRCRAFT LANDING PATHS FOREST FIRE ZONES AIR POLLUTION AREAS	USE-ZONED LANDS HISTORIC SITES ARCHEOLOGICAL SITES PARKS PUBLIC	STABLE NEIGHBORHOODS ETHNIC COMMUNITIES

Figure 15. Examples of Natural and Artificial Constraints Classed Into Three Groups (modified from Andrews, 1978; p. 200).

replacement of natural functions by artificial means. In the case of artificial constraints, hazards to human health and safety must be considered along with those laws, regulations, customs, or traditions which determine how any particular land resource is utilized or protected.

2. Discovery of Environmental Opportunities

This section utilizes the information provided by Section 1 above and the information organized by the classification scheme (discussed earlier in this chapter and in Chapter Four) to assist the planner in making decisions about how a land resource is to be used. By classifying ecosystems according to consistencies in land morphology, soils, stream patterns, plant associations, wildlife habitats, and land use, and recognizing the limitations presented by natural and artificial constraints, a listing of potential environmental opportunities can be identified. This stage of planning includes the mapping of use, development, and resource potential (for example, the identification of geologic formations which promise petroleum reserves or mineral deposits, forests with commercial-grade timber, or soils suitable for expanding agriculture). In addition, careful study of the information may present ways of converting constraints into opportunities. Forest areas prone to periodic fires may be managed for deer habitat by studying prevailing winds and regeneration potential along with judicial application of fire corridors. Unstable areas or floodplains might better be left in as natural a state as practicable to provide wildlife refuges or recreation while safer areas can be used more intensively for human benefit.

Studies can then be undertaken which examine the ecosystem according to its capabilities and suitabilities for particular uses. From an opportunity standpoint, these terms do not mean the same thing. A land area might prove capable of supporting a use (for example, intensive logging operations) but due to various ecological or social constraints, it might not be suitable for that use. The planner must account for all constraints when evaluating the environmental opportunities provided by an ecosystem.

3. Projection of Environmental Impacts

The purpose of analyzing and projecting the impacts or consequences of proposed actions is to determine how those actions will affect the components, structure, interconnections, processes, and resilience of ecosystems. While it would be nice to be able to predict what various activities will do (and, indeed, many simulation models attempt such predictions), it is more accurate and meaningful to be able to project with some degree of certainty how activities may impact ecosystems. Projection is a less precise action but it allows for a controllable amount of uncertainty which can accommodate more flexibility within a plan or project design. The projection of impacts is also used to examine a series of alternative actions and to help select the one alternative which is most acceptable according to decision criteria. By improving the ability to objectively judge among various alternatives, the value and acceptability of impact assessment methodologies and environmental impact statements (EIS) can be enhanced. The EIS can be a more useful decision-making tool as a result.

Ecologically Based Land Use Planning

Ecological land use planning is a science, technology, and philosophy in which decisions are value judgments (Hills, et. al., 1970). In order for ecosystems and their resources to be properly evaluated in terms of their capability, suitability, feasibility, and acceptability to planning and management activities, the necessary information must be carefully organized and integrated as well. Therefore, a planner must balance the information about environmental and institutional constraints, the opportunities presented by ecosystems for human use, and the assessment of impacts with the needs and values of both natural and cultural ecological principles. These principles, which will be discussed in greater detail in the next chapter, include maintaining functioning ecosystems and carrying capacity, preventing irreversible environmental changes, and protecting critical environments. Planners must be aware of these constraints when planning the use of ecosystems by directly utilizing information pertaining to these principles.

There have been numerous works on environmental planning and impact assessment in the last ten to fifteen years. However, very few authors have organized their methodologies around an ecosystem approach or have based their planning or assessment strategies on ecological information and principles in a systematic way. Harris and Williams (1975) and Holling (1978) advocate the organization of previously collected ecological information into systematic and iterative forms to facilitate its adaptation into mathematically powerful systems analysis models. Systems analysis based on the ecosystem framework was first advocated by Odum (1971). The primary intention of this information organizing is to develop an ecosystem-based conceptual framework that is accessible to ecologists who provide natural science information, data processors who develop mathematical simulation models, and decision makers who add political, economic, and social values to the total process.

Harris and Williams (op. cit.) and Holling (op. cit.) agree that much of the data collected is redundant and unnecessary. Instead of listing the presence of <u>all</u> forms of organisms and describing <u>every</u> physical situation, it is more important to examine the linkages between and among ecosystem components. The linkages provide an understanding of the components, how they are interconnected, and how they can be selectively manipulated without damaging other components and functions. Therefore, it is necessary to develop and administer a general set of principles and procedures for any planning situation rather than redoing a large portion of work with its high costs in terms of money and time. Data collected for one area can be applicable in another as long as similarities are noted. The time and money can then be spent on analyzing unique constraints and opportunities provided by the ecosystem and assessing the possible impacts of planning decisions pertaining to resource use. For example, communities of plants and animals and their habitats, including soils and climates, will <u>tend</u> to form similar ecosystems within the same biome regardless of whether the planning site is in northern Michigan or northern Minnesota.

Organizing information into a hierarchical structure based on Andrews' (op. cit.) application of environmental information (constraints, opportunities, and impacts) listed above is helpful in determining procedures and principles to be used in planning. The work by McHarg (op. cit.) was among the first planning methodologies to emphasize the inclusion of ecological processes within a hierarchy. An analysis of this methodology shows that environmental parameters including geophysical formations, hydrology, climate, soils, vegetation, animals, and humans are first studied separately and then integrated to discover possible incompatabilities, sensitivities, and suitable uses. To organize the study, a hierarchy is formed according to evolution of the parameters (from geological formations through humans) listed in the previous sentence. Consistencies in the biophysical parameters of one planning site or region are then compared with information already known about similar physiographic regions. Ranking within the hierarchy also depends on both natural and institutional values (and costs of replacing natural values according to social, economic, or political needs). Thus, the desired mix of ecosystem components (species, numbers, age, health, habitats, scenic quality, etc.) are, in part, determined by the superimposition of values on ecological limiting factors, especially natural processes that benefit humans. Throughout McHarg's interdisciplinary approach, called "ecological determinism," the importance of planning which recognizes biophysical processes is strongly emphasized.

McHarg has organized the information into a series of overlays and matrices which fit the Andrews (op. cit.) application scheme. Decisions about land use, site analysis, or amelioration of environmental degradation are determined by using the visual tools aided by analyses of suitability and compatibility of uses for each parameter in the hierarchy.

Other methodologies of value in ecologically based planning include total site analyses such as those developed by Way (1973) and

Marsh (1978). Way's (op. cit.) is the more pragmatic approach in that it examines sites according to their limitations on human use. Aerial photography and ground truth are used to identify the visual elements of various landforms (such as their topographic shape, drainage patterns, type of bedrock, vegetation, etc.), and then using this interpretation to solve planning problems usually via engineering technology.

Marsh (op. cit.) not only examines the physical constraints to site analysis, but also recognizes the need for an integration of data from all sources including remote sensing, ecology, engineering, social science, economics, and so on. Marsh recognizes that two kinds of knowledge are necessary in the planning process: (1) a knowledge of ecological systems and their functions; and (2) an understanding of the planning processes needed for each problem or task. Thus, he advocates planning the use of land areas through an integration of both processes. For example, a slope will be examined according to its geologic and geomorphic formation, the problems associated with it (grade, erosion, failure), and the types of uses it can support without incurring problems.

One other notable planning methodology is being developed in Great Britain (Hackett, 1971; Helliwell, 1973; Goldsmith, 1975; and Holdgate, 1978) and in The Netherlands and Denmark (Van der Maarel, op. cit.). Because the three countries are relatively small and densely populated, there has been increasing concern that rapid growth is causing reduction of natural ecosystems through conflicts of interest. The focus of planning efforts is to preserve as many natural ecosystem remnants as possible while encouraging natural development (secondary succession) on former nonnatural sites. It is felt that planning to enhance natural diversity and resilience can, in turn, positively affect interactions between the natural environment and society's demands. This environmental planning effort, called landscape ecology, consists of landscape ecological inventories, data processing, ecological evaluation, and impact analysis, and thus fits the criteria of the Andrews application scheme.

Plan Design and Implementation

The final steps in the planning process include plan design and implementation, with evaluation of those steps used to improve the design or seek better planning methods in the future. In order for an ecologically based land use plan to be meaningful and acceptable, it must be holistic, integrative, and ecologically sound. A holistic plan is one which examines all aspects of the environment (components, functions, structures, impacts) from a general viewpoint including the consideration of natural and institutional constraints. The ecosystem concept must be broadly based to express the relationships among the various components and subsystems, since it is these relationships which must be protected to preserve system integrity.

In order for a plan to be holistic, it must integrate ideas, needs, and information from as wide a variety of disciplines as possible. However, this integration of inputs must be organized to give the plan direction and cohesiveness. In doing so, the plan becomes both an administrative and communications tool. The plan should be a forum for the examination and solution of environmental problems and a vehicle for the realization of stated goals. The information needed to study the problem situation and adequately assess the various alternatives for its solution should be an integration of all pertinent sources.

Finally, the plan should be ecologically sound. Decisions should be based on the application of ecological principles which recognize that there are certain limitations to the amount and intensity of disturbances which neither natural nor cultural systems can tolerate. Ignoring or exceeding those limitations may result in expensive remedies, irreversible damage, or even total system collapse.

Multidisciplinary and Interdisciplinary Planning

Multidisciplinary and interdisciplinary approaches to planning have been advocated in the past. The multidisciplinary effort consists of a small-core decision-making staff which contracts parts of a problem scenario to specialists who are experts in those areas. Each specialist conducts his independent study which is then submitted to the core group for inclusion into the plan. The difficulties with this approach are the lack of integration and linkage among disciplines, a lack of expertise by the core staff to pull the reports together to reflect the important issues, and the development of static assessments characterized by large amounts of disparate information.

The second method is the large interdisciplinary team approach which attempts to interpret all the information gathered by each specialist. This approach often leads to a separation of the interdisciplinary team from policy makers and is expensive - financially, organizationally, and emotionally.

Holling Workshop Approach

The Holling Workshop methodology was developed as an alternative to traditional multidisciplinary and interdisciplinary approaches (Holling, op. cit.). Holling and his associates advocate a series of workshops which are run by an interdisciplinary core of two or three analysts (along with a small support staff), each of whom has expertise in several fields and can integrate information and coordinate specialists through methods such as mathematical optimization, and utility analysis; communications; and computer modeling of dynamic systems. Each workshop brings together 20 or so experts in a particular field for each stage of a planning task. The initial workshop includes scientists, managers, and policy makers working closely with the core group to identify problems, set goals and policies, define areas where information is needed, develop models and set the sequence of subsequent workshops. All elements of a planning situation (such as objectives, variables, management activities, indicators, time horizon, and spatial extent) can be considered and integrated into the planning model at the very outset of the program. Subsequent workshops may narrow their content to specific information areas seeking solutions to individual problems. For example, one workshop topic may include only land use and site analysis, bringing together methods and philosophies of McHarg, Marsh, and Way. Another workshop may consider only political, economic, or social aspects of a particular situation.

In between workshops, the core group consolidates the information and organizes the next workshop. Specialists gather scientific and other data as directed by previous workshop strategies. Each subsequent workshop further refines the planning model, incorporating aspects of ecology, management objectives, economic considerations, and so on. The ultimate goal of the Holling Workshop method is to connect various assessments of a problem; link the disciplines; involve scientists, planners, managers, and decision makers; and generate a range of alternative actions which are institutionally and environmentally acceptable and which can be tested and refined both quantitatively and qualitatively.

In contrast to traditional methods of land use planning which depend on the gathering of large amounts of data and then attempting to fit them to the problem situation, the Holling methodology integrates pertinent expertise and experience throughout the program in order to plan and design systems which can be compatible with, rather than against, existing systems. This approach gives the plan meaningful flexibility by allowing maximum participation (public and professional), adequate communication, and adaptable design. Holling calls this an "adaptive approach" in which plans or projects can be adapted or modified at any stage in the process to reflect changes in policies or the environment. Rather than spending time and money on studies which attempt to find out all there is to know about each situation and then developing a rigid plan (a static approach), the adaptive method realizes the value of examining and accommodating the dynamics of the environment.

The adaptive approach to planning is based on the theory of ecological resilience (Holling, 1973) which states that ecosystems can have various levels of stability depending upon the degree and intensity of outside influences, perturbations, or management actions. Resilient ecosystems will, generally, be dynamically stable as long as they can maintain equilibrium within their boundaries of stability (referred to as homeostasis). Many planning and management attempts have failed due to the fear that all uncertainties must be accounted for and eliminated. This short-sightedness has caused a collapse of stability boundaries. For example, a land or water resource is allowed only a narrow range in which it can maintain equilibrium because of some preconceived notion of stability (usually based on a static assessment of its conditions). Any perturbation or management activity which causes a shift in equilibrium beyond the preconceived stability region is considered disruptive or even irreversible. For all practical purposes, this is true. On the other hand, if an adaptive and dynamic approach to evaluating and planning that system had been used, it might have been discovered that the system was already in the process of change. That situation could have provided the knowledge to design a plan which was flexible enough to absorb changes when they appear and avoid disasters.

Adaptive planning policies can be helpful in project assessment by:

(1) projecting impacts which can be expected and identifying the major areas of uncertainty;

(2) listing the major ecological interconnections among components and processes which must be identified and monitored (or even controlled);

(3) allowing a continual review of impacts and planning strategies to promote plan applicability;

(4) realizing that uncertainties are a probability and that insurance or contingency funds can be established to allow the design of a project to be easily modified; and

(5) communicating to decision makers and the public that there will always be factors of a project which cannot be predicted, and that the planning process can adapt to inevitable changes by being flexible toward uncertainties.

Conclusion

The purpose of ecosystem planning is to guide human needs toward the best use of ecosystems - and this might not always be the best social or economic use. In the past, natural systems (and cultural systems existing in harmony with natural systems) have almost always yielded to pressures for development of resources. It must be recognized that there is a need for a proportional mix of natural and cultural values to allow diversity and stability within any ecosystem.

Ecosystem planning, when carried out according to ecological principles and constraints, actually becomes an evolutionary tool, both naturally and institutionally. Ecosystems can be planned, used, or preserved according to inherent needs as well as within guidelines of legal, economic, social, or other institutions. By directly altering different ecosystems, their components, and their processes, humans have inherited the ability to affect evolutionary trends with little understanding of the implications to their own evolution and survival as a life form. By allowing natural selection and evolution to proceed with relatively minor intervention, not only do we allow ecosystem diversity and resilience, but we may also enhance our own evolution by becoming aware of inherent meanings and values of natural systems.

In order to successfully plan the management of ecosystems, the structure and functions of ecosystem components must first be understood from a natural history standpoint. In other words, ecosystem planners must be able to recognize the important inhabitants and activities endemic to each ecosystem type which may be affected by human systems. This natural classification is based on inventory and monitoring to establish the inherent vulnerabilities and resiliences of natural systems. Ecosystems must then be classified according to their natural construction and their human components (McHarg, 1969). The history of man-nature interactions is then studied to define problems, identify needs, and predict trends in present and future uses of ecosystems. At the ecosystem level, the use of living and nonliving components and the impacts of such use can be planned to maintain a dynamic equilibrium.

Previous planning efforts have depended largely upon the complex of economics, politics, and industrial technology. The adoption of ecological principles into the planning effort will have a widespread and revolutionary impact on this complex. For example, a wetland ecosystem near an urbanizing area may be filled and developed into a site for a new power generating plant in response to political and economic pressures. It is recognized that wetlands provide some measure of water and silt retention which may help prevent flooding or pollution of other areas within the watershed. The industrial complex proposes to build water retention ponds on the site which simulate the physical presence and processes of the wetland. Consequently, people will have to pay for a service provided naturally (and free) by the ecosystem. In addition, no artificial holding pond would ever be able to simulate the diversity or stability of the wildlife populations within that ecosystem.

Each time a natural ecosystem is altered for human use, its functions have to be replaced by expensive technological systems. When trees are cut during a development project, their air purification and cooling effects have to be replaced by expensive and energy-wasting air conditioners. Productive soils and vegetation which are stripped from a construction site must be replaced at further costs to society. Extensive uses of sealed surface (roads, parking lots, etc.) not only increase water pollution from runoff, they also may require expensive storm sewers, enhance flooding, and reduce groundwater recharge potential of an area. All of these projects were designed for people's convenience but will wind up costing them much more than the original capital investment. As the environmental weaknesses of each development are perceived, people will begin placing more pressure on decision makers to alleviate the situation, usually with the result of more money spent and more technological control of the ecosystem.

Once the ecosystem plan has been designed, accepted, and implemented, it becomes necessary to manage the ecosystem or its resources according to procedures outlined in the plan. Ecosystem management must be based on ecological principles developed through the study and understanding of natural systems and utilized to guide the planning process. Chapter Six is a discussion of ecologically based management principles and how they can be applied in future man-nature interactions. Four major principles are identified and specific management guidelines based on the principles are detailed.

CHAPTER SIX

PRINCIPLES OF ECOSYSTEM MANAGEMENT

Introduction: Ecosystem Management as a Process

Management of any project or activity implies the skilled use of planning, organizing, coordinating, directing, controlling, or supervising a set of resources to achieve some desired goal (Webster, 1961). The general process of management involves goal identification, strategy selection (which includes the use of physical and conceptual devices), implementation, and assessment. The gathering of information is also needed and desired at each stage of management to aid the development and operation of specific management projects and to improve the efficiency of future activities (Rowe, et. al., 1978).

One important form of management is managing natural resources and the environments in which they are found. The goal of resource management as it is currently practiced is to utilize nature and the products of nature to satisfy the wants and needs of human society and its institutions. Resources are extracted and used if physically possible, economically feasible, and legally and socially acceptable (Barlowe, 1972). Technology provides the tools for implementation, and assessment of the management activity stresses the quantity of resource extraction and use.

Only since the passage of the National Environmental Policy Act (NEPA: PL 91-190 of 1969) has there been any real concern over the consequences of management decisions relative to natural resources. Prior to NEPA, natural resources were exploited according to the prevailing political, social and economic attitudes. Resources were strictly a commodity to be used or conserved, depending on the marketplace. Natural ecosystems could enjoy long-term protection only if they were preserved in national or other parks; all others were subject to short-term or long-term exploitation. It may be argued that no natural ecosystem has fully escaped human influence as long as there were potential resources to be extracted from it. Many of our so-called primitive areas are actually second-growth forests which proceeded through natural succession following the cessation of logging or agricultural operations. It may be a cynical viewpoint, but nearly all of our woodlots, wetlands, prairies, deserts, and so on exist in their present state only because their potential for economic exploitation was not as high as in other areas. As a result, large acreages of natural and near-natural ecosystems still exist in the U.S. and other countries. The primary concerns of present and future resource management are what we plan to do with such areas and how we are going to do it. To a great extent, the solution to this dilemma will depend on reasonable management goals and strategies in relation to the state of human society and its wants and needs.

During the 1960s and 1970s, the environmental aspects of resource use began to be considered along with economic and engineering criteria. With the passage of NEPA and other environmentally oriented legislation, resource use, project implementation, and development plans had to be assessed as to their impacts upon the environment. Because such developmental activity affected the living and nonliving components of both human and natural environments, there became a greater need for ecological understanding, especially at the ecosystem level (Odum, 1971). Nearly all of the areas of resource management, regardless of their mix of human and natural influences (see Chapters Four and Five), involve a combination of ecosystems which will require an ecosystem management strategy based on ecological principles.

The term ecosystem is used to denote natural or human systems which are open to material and energy flow, comprised of living and nonliving components interacting with each other in a dynamic, self-perpetuating complex (Tyler, 1975). Ecosystem management is based on the theory that the ecosystem is the basic living system in which the relationships between living things and their environment can best be understood and, if necessary, manipulated for their own protection or for human needs. Because of the complexity of ecosystems and the number of demands placed on their resources by human needs and desires, the management of ecosystems requires an interdisciplinary effort - management decisions and processes affecting ecosystems have ecological as well as economic, social, and engineering aspects. Each of these areas of interest is important and must be considered in the manipulation of ecosystems. It is the responsibility of the ecologist, however, to define the ecological principles by which such manipulation is governed. Decisions must be based on ecologically sound principles to ensure that the ecosystem processes affected by a project are not doomed to irreparable alteration.

Any management process is based on a series of concepts and philosophies which have evolved as a result of management goals reflecting the problems of a clientele and the best methods for their solution. Ecosystem management has come about through a human need for natural resources for a higher standard of living and a rising concern for environmental quality. Management of the natural ecosystems requires a choice of either quick exploitation of resources for dramatic increases in the standard of living (along with little respect for ecological principles) or more gradual increases through long-term and ecologically sound management. It is also the responsibility of the ecologist, who is part of a management team, to provide the conceptual framework for the systems analyst (who is attempting to simulate an ecosystem to be managed), the conservationist, the land use planner, the economist, and the engineer. The primary purpose of this chapter is to establish a conceptual framework for ecosystem management to assist planners, managers, and decision makers in asking appropriate questions, understanding ecosystem components and linkages, finding solutions which are ecologically intelligent, and making the correct, long-term decisions for the advancement of human systems and protection of natural systems.

Concepts of Ecosystem Management

Ecosystem management has gained impetus primarily through the efforts of Watt (1968, 1977), Van Dyne (1969), Dasmann (1976), Odum (1975), and Holling (1978). These authors have stressed the importance of the ecosystem concept as the framework for managing resource use and conservation. Ecology can provide the guiding principles for management through an understanding of the components and interconnections inherent to living ecosystems, careful study and simulation modeling of the ecosystem parts, and projection of impacts from human manipulations. In order for ecological principles to become a viable guiding force in management, however, a conceptual framework is necessary. Harris and

Williams (1975) argue that without such a framework, systems methods including mathematical and computer modeling, simulations, or systems analysis applied under an "ecosystem concept" are invalid and ecologically dangerous.

Therefore, in order for present methods of resource planning or management to be both successful and ecologically acceptable, an ecologically based conceptual framework must be the foundation for manipulating ecosystems whether via computer or bulldozer.

There are several important principles or goals which underlie a conceptual framework for ecosystem management. Briefly, these include the need to:

(1) work within ecosystem constraints (a functioning ecosystem provides a good measure of environmental quality);

(2) adopt and maintain a long-term carrying capacity approach to resource management in both natural and artificial systems;

(3) prevent irreversible environmental changes; and

(4) protect critical environments and habitats.

Working Within Ecosystem Constraints

A thorough understanding of theoretical ecology is neither necessary nor practical for ecosystem management to function properly. On the other hand, the ability to recognize the interrelationships among important ecosystem components *is* necessary in order to manipulate them. The ability to identify the appropriate ecosystem components, understand their importance, and visualize the functional interconnections among them is a necessary initial step. Once this identification has been made, specific parts of each ecosystem can be isolated and further studied depending on the needs of the management activity.

A review of the preceding four chapters shows, in a general sense, a framework which can be used to establish an adequate ecosystem study or management activity. Chapter Two provides a description of ecosystems as living, functioning systems, which are made up of interconnected subsystems. Each ecosystem is powered through a complex of energy transfer and matter cycling among its various endemic organisms. One of the major goals of ecosystem management is to maximize the productivity of this energy-matter-organism complex by maximizing populations of desired species and minimizing populations of undesirable ones (Watt, op. cit.). This goal can be accomplished through a common set of processes including dispersal (spreading the population out over larger areas to better utilize space and nutrients); organism interactions such as predation, competition, or parasitism (using one population to control another); or habitat modification (making the environment either more or less attractive to an organism).

The concept that "everything is connected to everything else" is introduced in Chapter Two and reinforced more intensively in the study of cycles in Chapter Three. The Energy-Matter, Abiotic-Biotic, Population, and Community Cycles described are all dependent on ecological properties. In these cycles, processes affect the components and the components determine which processes will occur. Therefore, management of each ecosystem will depend on which components and processes are to be manipulated, protected, or simply monitored. Careful study of a particular cycle will allow some starting point from which an ecosystem can be simulated to allow projection of an impact throughout the system

which may be affected. Figure 12, the conceptual model of a general ecosystem, then allows the ecosystem manager to place his manipulation or any other activity within an overall perspective.

Ultimately, ecosystem management must include the human element within its actions, as has been done in Chapter Four. All ecosystems have some degree of human activity or influence or must accommodate human use. Resource use or procurement involves the ecosystem since the ecosystem provides much of the organic and inorganic resources used by human systems. Human systems (cities in particular) are dependent on maximum productivity in which the inputs of energy and land resources are used most efficiently to produce maximum biomass and the most usable numbers of size/age classes of organisms. This can be done only through maximum production or minimum wastage (Watt, op. cit.). Nearly all of this activity is controlled by the same ecological principles (Chapter Three) that govern the more natural ecosystems.

In addition to Watt's management principle of maximizing productivity, there are several other general ecological principles which have management implications. The first four are paraphrased from Holling (1978; pp. 25-27) while the fifth has been adapted from Harris and Williams (1975; p. 201):

(1) Everything is connected to everything else - but not always very strongly. There is no inherent or obsessive need to measure or list everything within an ecosystem, although a determination of the significant connections <u>is</u> necessary. For example, manipulation of a habitat utilized by a simple community may affect only a small portion of the organisms, but <u>how</u> they will be affected and the subsequent impacts elsewhere

may have to be quantified. In addition, knowing structural features such as size distribution, age, or species interconnections provides a better understanding of the relative health of a population of organisms than either a total census or a species inventory.

(2) Impacts of management activities are not always predictable and they are not always gradually diluted over space. Changes in variables can result in impacts on variables with seemingly unrelated aspects (i.e., the interconnections were "loose" and not properly studied). This holds true for the synergistic effects of two chemical pollutants. It would be assumed that upon introduction into the environment, both would become diluted over time and space. However, the combination of the two in dilution may have a more serious effect than concentrations of either by itself. It is difficult to measure impacts because of variability in the structure of organisms; movement of energy, matter, or organism dispersal; or vagaries in physical forces such as winds, currents, erosion, etc. An understanding of the uncertainties will allow monitoring of the proper variables and hopefully prevent inaccurate or inappropriate simulation.

(3) Sharp shifts in behavior are natural for many ecosystems because nearly all such shifts can be accommodated by an inherent resiliency in ecosystems. In other words, not all natural ecosystems are as fragile as once believed. (Odum (1975) suggests that cities, which are critically dependent on the health of other systems for food, energy, and materials may

be the most fragile ecosystem of all.) It is necessary to design management activities or development projects which can adjust to changes or uncertainties rather than limiting the available options.

(4) High levels of variability and diversity rather than constancy are an ecological attribute which contributes to the ability of an ecosystem to be self-regulating and self-perpetuating. Change is a viable force in nature in which the system is constantly tested by a multitude of events. Elimination of change or uncertainty even under the goal of "improving environmental quality" may lead to a decrease in ecosystem resiliency and renewal ability.

(5) The evolutionary process of natural selection is the only long-term way that organisms can adapt to the unpredictability of the physical environment. The understanding and aid of natural selection must replace artificial selection in the management of natural systems. In less natural systems, artificial selection must be based more strongly upon an ecological basis rather than on a strictly commodity basis.

Adopting and Maintaining a Long-Term Carrying Capacity Approach in Resource Management

The concept of carrying capacity is central to both ecology and ecosystem management. It is an important process in ecosystem cycles (Chapter Three) and the major ecological feedback mechanism as illustrated in Figure 12. As was previously mentioned, a general definition of carrying capacity is the ability of a habitat to support a maximum population over a period of time. This is dependent on available resources (space, inorganic and organic nutrients, productivity, etc.) which, together with species interactions, accessibility of an area, and physical and chemical factors, become limiting factors to the growth, abundance, and distribution of organisms. Populations of organisms are naturally controlled through either their tolerance or intolerance of factors which define the carrying capacity. Likewise, the management of such factors will also determine populations within an ecosystem.

Unfortunately, carrying capacity no longer has a single meaning. Gotschalk and Parker (1974) state that the concept of carrying capacity must be expanded in order for it to be important in resource and environmental management and planning. A more contemporary meaning of carrying capacity is the ability of both natural and man-made systems of an area to support the demands of various uses. Inherent limits still remain beyond which change and adverse impacts cannot be absorbed without resultant instability, degradation, or irreversible damage. Recently, humans have been able to exceed physical limits only through massive inputs of technology and at the expense of health and safety. Throughout the world, populations have grown so large that their demands on present food, shelter, or energy supplies have exceeded both natural and simpler technological carrying capacities. The increased use of fertilizers, petrochemicals, nuclear energy, and so on, may eventually lead to irreparable environmental and evolutionary damage.

There are three classifications of the carrying capacity approach to management (Bishop, et. al., 1974; Gotschalk and Parker, op. cit.). Each one requires a set and managed level of activity (carrying capacity) which can be permitted. In essence, this represents a generalized classification of ecosystems according to human use (see Chapter Four). The three types of application include:

(1) areas of limited use - relatively more natural areas which cannot tolerate significantly increased human impact would have their carrying capacity limits set before any alterations are caused (parks, wilderness areas, scenic strips, etc.);

(2) areas of managed use - ecosystems which can tolerate change of certain aspects as long as the overall environmental quality is not degraded; resources are allocated and their extraction or use must not upset the predetermined carrying capacity (mining, forestry, etc.); and

(3) areas of self-limiting use - massive changes can be tolerated up to but not including total system collapse (urbanization, clearing new lands for agriculture, etc.).

Carrying capacity limits for each of the above categories are determined by ecological theory and what Gotschalk calls perceptual and institutional carrying capacity. These last two concepts are determined by human perception of a desirable environment and by the ability of institutions to guide development reflecting the goals and values of the public. Therefore, the carrying capacity threshold can be crossed only through collective design or expensive public investment. Central to this philosophy is the knowledge that natural resources are not inexhaustible nor are natural systems able to withstand impacts without some change.

Prevention of Irreversible Change

From an evolutionary standpoint, change in natural ecosystems is essentially irreversible. This is desirable and necessary because change is a continuous process which is a feedback or regulatory mechanism. Change and variability in dynamic ecosystems can absorb disturbances by shifting to a new equilibrium point. Thus, the system maintains some relative stability over time. Human activities have usually been an attempt to add "stability" to natural systems. The naturally occurring change or variability is contrary to the human need for predictability (e.g., flood control structures, weather modification, forest fire prevention, genetic breeding, etc.). If the variability is constricted to the point where the various states of equilibrium become unknown, the system may collapse, and the change then becomes irreversible.

As was previously mentioned in Chapter Four, there are numerous examples of irreversible changes that have occurred as the result of ignorant ecosystem manipulation. The most infamous have been the extinctions of plant and animal species caused by overhunting, destruction of habitat, or the inability of native species to compete with exotic species. Creation of urban landscapes with roadbuilding, sealed surfaces, channelization of drainageways, and the use of biologically toxic materials is another example of irreversible change. Earth-sculpting activities such as roadbuilding or dam construction have modified geologic structure and geomorphic processes, as well as affected the organisms dependent on that habitat.

It is not necessary for ecosystem management activities to restore the <u>original</u> condition of an ecosystem, nor is it always desirable or even possible. It is essential, however, to restore the ecosystem's dynamic equilibrium (Watt, et. al., 1977). This can be accomplished by recognizing, controlling or preventing activities that are disruptive (see previous paragraph), particularly those which upset homeostasis (dynamic equilibrium). A thorough understanding of the components and their interconnections, especially those which are most vulnerable to failure, is a necessary first step in the management process. A logical second step is the maintenance of community and habitat diversity, subject to natural rather than artificial selection.

A major aim of ecosystem management is to promote and sustain optimal productivity within the limits of carrying capacity, and it must be realized that improper manipulation of the population growth equation may lead to irreversible change (May, 1978; p. 11). This is illustrated in the equation below which states that the change of a population over time is the result of population size multiplied by growth rate, which is affected by conditions of the environment:

$$dN/dt = rN\ (K - N/K)$$

where:

$N(t)$ = population numbers at time t

K = homeostasis (carrying capacity)

r = rate of growth

Populations with a large diversity (such as most birds and mammals) which are dependent on carrying capacity (K) have difficulty recovering from a disturbance outside their evolutionary experience. Populations, particularly insects and pest species, which have the ability to adapt to environmental disturbances, usually have a high growth rate (r) and can recover from bad times and exploit good ones. Manipulation of populations must therefore include elements of diversity, relative stability, recoverability, and productivity as well as profitability (Watt, op. cit.).

Schumacher (1973) coined the term "appropriate technology" in describing how developing countries should use their resources most efficiently. That term is applicable in managing any ecosystem, whether natural or artificial. The continued use and expansion of technologies which do not irreversibly alter natural systems or make human systems less tolerable are "appropriate technologies." Reliance on the "technological fix" will become increasingly expensive and, often, the solutions to environmental problems are worse than the original problems. This indicates the need to understand ecosystems holistically and design technologies which do not put pressure on the existing carrying capacities of various environments. Ecosystems which require full protection should be subjected to little, if any, technological impact while those which are largely artificial must rely on a high technology for their survival and vitality. Thus, ecosystems and their resources can be classified, planned, and managed according to their technological requirements for maintenance in addition to their components, interconnections, and degree of human activity.

Activities which limit ecosystem resilience by reducing diversity, variability, or change will invariably lead to irreversible system breakdown. Resource management, which has allowed resource transformation at rates too rapid for natural accommodation, has contributed to disrupting dynamic equilibrium (Tyler, op. cit.). Examples include strip mining, timber clearcutting, air and water pollution, and radiation. Although none of these activities are truly irreversible, they have caused rapid change which is often difficult to be assimilated or ameliorated in ecosystems. These may have indirectly led to irreversible changes of which we are not even aware yet. Management of such resource transformations must necessarily become more important in the future through careful research and monitoring.

Protection of Critical Environments

There are certain combinations of habitats or environments which are essential for the long-term well-being of plant, animal, and human populations. Such habitats are termed critical because they supply limiting factors for a population. From an ecological standpoint, the habitat provides a food supply and cover for traveling, eating, watering, sleeping, breeding, and rearing young (Jain, et. al., 1977). The presence or absence of a species in any particular geographic area depends on accessibility of the area, whether the area has preferable habitats, interaction with other species, and the species' tolerance to physical and chemical factors (Krebs, 1972). An environment which has the proper requirements for a particular species is essential for that species. If there are only a few such habitats available, they become critical for that species. For example, jack pine habitats of a specific age and size class in northcentral lower Michigan provide the only known nesting areas for the Kirkland's warbler. It, therefore, is a critical habitat; without this nesting area, a single species of bird might become extinct.

There are several categories of critical or essential environments which have been defined based on economic, social, political, and ecological criteria (Barlowe, 1976). These include:

(1) Prime agricultural and forest lands. Rapidly growing world populations are making greater demands on food, fiber, and shelter resources. Areas within heavily populated countries which supply resources are already intensively used and are critical for each country. A few countries have exceeded the carrying capacity of their best lands and are expanding resource development into marginal lands (if such lands are available). In other countries, the rapid expansion of urban areas threatens valuable farmlands and forests which may have to be used to meet future needs. Agricultural and forestry areas are critical from a human standpoint and are managed according to a mix of economic, social, and political decision-making criteria.

(2) Open space; recreation areas; scenic vistas of natural landscapes; and areas of cultural or historic interest. Such areas have become essential in adding quality to the human existence and spirit. They are also critical in that such areas have felt pressures from development for greater economic benefits.

(3) Oceanic coastal zones and estuaries. Many long-range plans for feeding world populations include recommendations for more intensive development of the ocean's fisheries. The highest productivity within the oceans occurs in coastal zones with nutrient upwellings and in estuaries which allow a mixing of fresh and salt waters (Odum, 1971). For all practical purposes, the open oceans are vast biological deserts. The most highly productive areas are being destroyed by pollution or

becoming nutrient-deficient by current urbanization. If the projected use of coastal zones and estuaries are to be included in future plans, they must be designated essential and critical.

(4) Freshwater wetlands and recharge areas. Both areas are essential in replacing groundwater supplies depleted by pumping for human use. In addition, wetlands provide valuable spawning and nesting grounds, a nutrient-mixing zone, and a floodwater buffer. Unfortunately, during most development activities, wetlands are the first to be converted by dredge or fill to other uses. As far as recharge areas are concerned, many have been eliminated by sealing the ground surface before much was known about the physics of groundwater recharge.

(5) Unique ecological, geological, and topographical areas. Such areas, once removed or destroyed, are irreversibly altered because the forces or processes which contributed to their formation operate over very long periods of time (from the human point of view). These areas have developed through evolutionary processes such as natural selection, erosion, or crustal deformation of the earth. Elimination of a habitat also eliminates the organisms which depended on that habitat for life-giving resources. No amount of site restoration after mining or highway building can duplicate the landscape that took ages to form.

The identification and designation of land and water areas which are critical or essential to present and future resource needs is a controversial management problem. It is even more of a problem to induce people to recognize the importance of critical areas and to protect such areas from irreversible exploitation. The decision to alter, manipulate, or manage essential and critical environments depends to a great extent on human needs and values. Short-term goals for economic or political gains may preclude the preservation of critical areas while long-term, public interest viewpoints seek to measure essential areas as resources rather than commodities and see such resources as fundamental for human survival (Libby and Newman, 1977). Besides producing food, fiber, and shelter for growing populations, critical or essential environments also:

(1) provide scientific knowledge of the structure and function of living natural ecosystems (such knowledge can also support baseline studies of environmental quality and act as a model for human ecosystems);

(2) preserve gene pools and a healthy diversity of organisms; and

(3) promote education, training, and research opportunities to help solve future problems (Watt, et. al., 1977).

The requirements of NEPA demand that projects involving impacts to natural and human ecosystems include an assessment of such impacts. In many cases, critical natural areas and cultural areas (e.g., prime agricultural, historic, or resource-bearing, etc.) have been preserved if only as the result of caution. Due to ignorance or unconcern, many such environments have been lost. As Watt (op. cit.) mentions, protection and study of functioning natural ecosystems may take part of the measure of uncertainty out of decisions involving essential areas. Understanding the functions, changes, and resilience of natural ecosystems allows planners and managers to apply such knowledge to the development of human systems, since they are governed by the same basic natural rules.

While it is obviously important to protect and enhance environments which provide resources necessary for human existence, it may be equally important to preserve a diversity of natural environments for their potential to provide future benefits. The oft-repeated cliche that a presently unknown or obscure species may be the key in the cure of cancer has been a powerful argument in the protection of endangered species or habitats. Although such an example may be extreme, it does illustrate the necessity of preserving as much natural and cultural diversity as possible.

A Philosophy for Ecosystem Management

The conceptual framework for ecosystem management is based on a management philosophy which (1) provides the decision-making path least environmentally disruptive in human-nature interactions; and (2) directs human processes as parts of evolving nature as opposed to intrusions upon it (Garlauskas, 1975).

Environmental Decision Making

The first part of this twofold philosophy recognizes the human point of view in ecosystem management to assure survival and progressive improvements in the quality of life through maximizing productivity and minimizing loss of valuable and essential resources. This is done by adopting the following management guidelines:

(1) Promote the rational use of resources. Nutrients, minerals, and biomass naturally cycle through ecosystems in a fairly

slow and predictable manner and are used by living organisms as they are needed or become available. Human activities, particularly those employing sophisticated technologies, have caused a divergence from natural cycling where resources are transformed in space, in magnitude, or into other things at rates which are too fast for natural accommodation (Tyler, op. cit.). From an ecological standpoint, this has caused a destabilization of homeostasis. From a human standpoint, it has resulted in a poor distribution of resource benefits on a worldwide basis and a decrease in a livable environment. Methods which have been proposed to alter present resource use have included recycling, conservation, adoption of appropriate technologies, and redistribution of wealth. A combination of such methods is recommended although future success of any management activity can only be achieved through worldwide population control (Harris and Williams, op. cit.).

(2) Adopt a conservation ethic. The rational use of resources also requires a commitment to conserve remaining resources for long-term availability and benefit. Dasmann (1975) calls conservation a point of view and necessary line of action concerning the environment and its inhabitants. The realization that varied ecosystems and their resources are vulnerable to an exploitive, nonconserving philosophy must become part of a widespread effort of ecologists, educators, politicians, economists, and engineers. Conservation practices must also be based on a comprehensive understanding of ecological principles which operate on a long-term evolutionary timetable

rather than on a short-sighted economic one. Each species' survival and well-being is dependent on the long-term productivity and health of the entire system. Elimination of system components through lack of conservation efforts upsets the processes which organisms depend on, thus upsetting system balance (as well as eliminating potential resources to meet the needs of future generations).

(3) Limit activities that impair the long-term well-being of other humans, other species, and the environments on which all of these depend. The inherent value of maintaining a maximum number of diverse ecosystems and organisms has been pointed out several times in this paper for the humanitarian goal of providing opportunities and alternatives to all people and on the expanded ethic of dealing with natural systems as we (theoretically) have learned to deal with the wide variety of human cultures and philosophies. In other words, maintaining diversity and resilience are crucial ecological principles which apply to both natural and cultural ecosystem management. Activities which limit diversity and resilience may (and probably will) lead to system breakdown.

(4) Manage the environment to support optimum populations (human, wildlife, plant) within the carrying capacity. Because maximum productivity is desirable from a management standpoint, we wish to promote useful species (on a human value scale) and discourage undesirable species. However, the carrying capacity of the particular ecosystem with which the desirable organism is associated must be used in the calculation of what

the optimum population can be. In order to determine the carrying capacity, it is necessary to examine each species' position in the trophic structure (for efficiency of matter and energy conversion), the species' growth and reproductive structure, available habitat (food, water, shelter), and the successional stage of the habitat (early successional stages are characterized by relatively high productivity while climax stages tend to be more stable (Odum, 1975)). Exponential growth of demand, consumption, and waste have seriously affected the ability to manage ecosystems to produce food and other resources and assimilate wastes, thus limiting human carrying capacity and reducing the potential of maintaining diverse natural ecosystems to an extravagant luxury (Morse, 1975).

Nature-Human Interdependence

The second part of the ecosystem management philosophy stresses that human and natural ecosystems and their processes are interdependent. Human systems, therefore, must evolve along with natural systems. On the other hand, evolution is an extremely slow process, and our impatience has led to an acceleration of evolutionary functions which results in the extinction of a species or alteration of successional stages. It is necessary for planners and decision makers acting as ecosystem managers to recognize, predict, minimize, and control activities which cause stress or irreversible changes.

Nature-human interdependence can be achieved through the development of a usable conceptual framework for ecosystem management and the

implementation of a systematic, scientific, and holistic approach to problem solving. The conceptual framework will provide a means for managers with widely diverse backgrounds to achieve a common understanding of the ecological systems and processes their manipulations may affect. It can also assist as a communications device in an interdisciplinary team effort, especially among ecologists, mathematicians, and systems scientists. A conceptual framework includes an explanation of the management problem, how and why it came about, the various alternative solutions and their impacts, a recommended course of action, and the philosophies and constraints which influence the problem solution. The framework also includes background material which is general enough to be accessible to a large and diverse audience and sophisticated enough to provide a good, basic education of the subject through description, examples, and references.

A systematic, scientific, and holistic approach to problem solving is a useful method of integrating all components of both human and natural ecosystems regardless of their assigned human values. A systematic approach allows the discovery, evaluation, and quantification of ecological components and processes which pertain to the specific management problem. Scientific approaches provide the means by which selected components and processes can be experimentally manipulated, the results being useful in forming hypotheses, generalizations, or projections. Finally, a holistic approach allows the manager to view both the ecosystem and the manipulation efforts from a total perspective, in which impacts are visible at the site of manipulation and, more importantly, in other areas within the ecosystem where they might have deleterious effects.

Developing an Ecosystem Management Methodology

The primary goal of an ecological management methodology is to promote and ensure appropriate land use for the future. This goal can be realized through the development and utilization of management programs which integrate information provided by research, planning, and an identification of society's wants, needs, and expectations concerning natural resources and ecological systems. In developing a management program, whether it is for multiple use of government land, the propagation of a species of gamebird, or the construction of a new community, the ecosystem manager must base the program on certain guidelines. These guidelines will allow the manager to ask appropriate and meaningful questions regarding program goals, problems to be solved, policies to be developed, institutional and natural constraints, and the long-term implications of alternative decisions.

Problem Definition

The first question a management methodology must address is in the definition of realistic problem boundaries. This is done to organize information and expertise while establishing the proper scale of operations. A broad-based and general program may attempt to answer all questions and address the needs of all interests, but it may not be able to solve all of the related problems to everyone's satisfaction. Air pollution control is a good example. Government agencies like the EPA must contend with domestic, industrial, and automotive pollution while, at the same time, be constrained by inconsistencies in social priorities, jurisdictional disputes, changing standards, and other interrelated problems (Sewell, 1975). A scale which is too constricted may address major problems but unintentionally ignore related problems or areas of interest which should also be examined.

It is also necessary to describe the desired situation or, in other words, the optimal pattern (in an ecological sense) of land use. This will require a careful balance between the environment's potential and society's demands. Managers must ask questions concerning desired levels of environmental quality, optimal populations of organisms including humans, habitat quality and carrying capacity, and land capability and suitability. Information gathered during the planning process will be helpful in designating the necessary adaptations natural and human ecosystems must accommodate, the required degree of intervention in natural processes, and the hazards and consequences a management activity may encounter (Collier, et. al., 1973; Jacobsen, 1978).

The problem definition phase of a management methodology involves people and a careful coordination of the interests they represent. The manager must evaluate and implement inputs from decision makers and those who live with the decisions, changes in consensus and environmental priorities, and an equitable distribution of costs and benefits. He must also coordinate the efforts of his planning and management staff to ensure that relevant questions are adequately addressed. This continued involvement in the needs of people will require flexibility to changes which may include modification, revision, or additional investment in terms of time or money in the development of the project. By carefully outlining the potentials and constraints on any project in the management methodology, the ecosystem manager can enhance communications among the various interest groups and develop a dynamic and ecologically sound program.

Information Base

Holling and Clark (1975) state that an ecological management program requires a sound empirical base to discover and understand causal relationships which link organisms with each other and with their environment; from there, simulation models can be constructed to address real-world problems. They go on to say that past management efforts have relied on trial-and-error strategies due to deficiencies in ecological information. As long as the consequences of the activity were minor and alternatives remained, such attempts added to the store of knowledge. Another strategy concerned "engineering out" or overcoming natural constraints in environmental problems via the technological (energy and materials) fix, which is still advocated and practiced.

Such strategies attempt to ignore ecological principles with the hope that they might go away. It is becoming more apparent that the magnitude of environmental problems and current attempts to solve them cannot continue to increase without disastrous results. Questions the ecosystem manager must ask involve evaluation of the scale of the problem situation and of the information which is known and that which needs to be found out. He can then adapt tested management policies or formulate new ones according to the identified needs and goals, institutional and natural constraints, alternatives, and unknowns. Thus, the management methodology can fit the problem area at the proper scale and intensity, conserving resources and impacting only the desired portion of an ecosystem.

Strategy Selection

The goal of ecological management strategies is to develop holistic, integrated, continuous, and updatable management programs within the framework of ecological theory. The selection of a specific strategy will depend on the management situation, its implications, and associated problems. On the other hand, there are certain components which should be common to all ecological management strategies; these include the following:

(1) A conceptual framework which provides the theoretical base for understanding ecosystems from orientations of systems science, ecology, institutions, and so on (Chapters Two through Six);

(2) A survey or inventory to provide the manager with physical information of the ecosystems affected by the management program; this may include classifications or base maps which indicate land capability, suitability, present use, etc. (Hopkins, 1977; Dorney, et. al., 1979);

(3) An environmental assessment and analysis (which is part of the planning process) to examine the state of the ecosystem and establish its resilience to potential impacts or management manipulations, establish an idea of environmental carrying capacity for desired plants and animals, set limits on levels of productivity and energy requirements, and quantify ecosystem homeostasis (Odum, 1969);

(4) Ecological indicators to provide the manager with evaluation tools would include diversity, relative stability, degree of naturalness, abundance or scarcity of species, habitat quality, susceptibility to disturbance, etc. (Van der Maarel, 1978);

(5) A description of techniques which may include (a) changing species of organisms present, (b) modifying ecosystem structure, or (c) changing ecological conditions (Ovington, 1975);

(6) A description of tools which can be modified to fit particular ecological situations such as environmental impact statements (Hopkins, et. al., 1973; Heffernan, 1975) or impact networks and matrices (Leopold, et. al., 1971; Thomas, Davis, and Humphrys, 1978);

(7) Implementation guidelines which would include a summary of management activities along with a timetable indicating when each activity will occur, its duration, and expected results. Implementation would also include provisions for public and agency participation, program evaluation, and safety factors; and

(8) Monitoring to provide prompt and critical reviews of the management program and a continuous source of information to appraise the manager of the state of the ecosystem and manipulation activities (Holt and Talbot, 1978; Heffernan, op. cit.).

As discussed in Chapter Five, Holling (1978) has advocated an adaptive approach to planning and management in which information is gathered and integrated to address a particular ecological management problem. This information is then organized according to its ecological fitness and relevance and then tested in understandable ecosystem simulation models. The purpose of this extensive data gathering and intensive testing is to allow the ecosystem manager to project how an ecosystem may react to management inputs. In doing such tests, the manager is looking for indicators about the ecosytem which will help him design

programs which are ecologically sound as well as satisfying the requirements of society. By noting the system's resiliency and the variability of equilibria within resiliency boundaries, the manager can integrate this information into the design. Such a program exhibits enough flexibility to absorb surprises caused by unknown factors - either natural or institutional.

The importance of ecosystem monitoring must be stressed in order for an adaptive management program to be successful. Monitoring of the environment in the assessment and management process continues to provide information about system resilience and is a good method of providing a check on those indicators which signal when system stability is being threatened. Human activities and ecosystem conditions must be monitored continuously to allow modification of management programs so the programs can adapt to changes as they occur and, thus, contribute to the fitness of the program in both natural and cultural systems.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

The ecosystem concept has been advocated as a fundamental unit in ecology. The ecosystem is defined as the physical location where living organisms interact with each other and with their nonliving environment. Functioning natural ecosystems are areas on the earth's surface where complex processes such as energy flow and nutrient cycling occur and lead to production of biomass from the primary process of photosynthesis (green plants) and secondary productivity through chemical respiration (generally animals). Populations of living organisms are dependent on the resources provided by their environment and will adjust their numbers according to the availability of food, water, or shelter through feedback mechanisms such as carrying capacity, population interactions, community succession, and homeostasis.

Ecosystem components, whether living or nonliving, are connected to each other by processes, functions, or interactions to form complex subsystems. Ecological systems are open, natural systems with respect to material and energy movement. Their operation as whole entities is dependent on the flow of resources and on the mechanisms which provide stability to ensure self-perpetuation. Homeostasis, the "balance of nature," is dependent on adequate resources to support life, organisms' abilities to utilize the resources for growth and reproduction, and resilience to any disturbance within a range of stability. Natural

ecosystems have the ability to resist change, but are slowly and constantly changing through evolutionary processes (such as changes in climate, random mutations, natural selection, and so on).

Because of individual differences in their make-up and unique environmental factors, each ecosystem is different from any other. However, all ecosystems behave according to set principles which allow generalization and interpretability. The intention of every ecological investigator is to analyze an ecosystem and then utilize the principles to formulate a model which resembles reality. Accurate ecosystem models with valid predictive powers are valuable tools in monitoring, evaluating, and managing ecosystems for human use.

Reichle (1975) states that ecosystems are not a hypothetical concept, but a working principle with tremendous potential for addressing environmental problems or for providing long-term resource availability for human needs. Since most of the earth's ecosystems have been significantly altered by human use, we can no longer maintain a hands-off policy (Southwick, 1976). By following ecological principles in our dealings with the environment, we can adopt an ecosystem approach to problem solving.

There have been numerous attempts at formulating accurate, predictive models which can be used in ecosystem planning and management. Most, however, are special-case models, while a need exists to develop complete and comprehensive models which can be applied to any ecosystem, large or small. Such a model can be precise in that it attempts to be consistent and repeatable. It should also be as near to reality as possible and be holistic by containing as many variables as possible. While it would seem that a reduction of variables would make the model less cumbersome, the very nature of natural ecosystems precludes this oversimplification.

The oft-stated ecological principle that "everything is connected to everything else" (Commoner, 1970) requires that activities done in ecosystems be carefully monitored to prevent adverse impacts. This essential interconnectiveness is a result of the cyclic nature of ecological processes. Unless upset by either natural or human influences, ecological cycles tend to remain circular and move linearly toward homeostasis. These homeostatic cycles include:

(1) Energy and matter movement - including energy flow from the sun or from chemical bonds and which drives the cycling of matter between organisms and the environment. This cycle provides the requirements for survival and thus determines which ecosystem components will be present in an area, the ability of the environment to support populations (carrying capacity), and the rate of change in the environment.

(2) Population dynamics - which includes parameters such as population growth, change, and interactions which are dependent on the environmental carrying capacity, natural selection, and evolution.

(3) Community dynamics - which are determined by the combinations of populations and state of the environment. Changes in both parameters will change the community slowly over time until the community as a whole reaches an equilibrium state known as the climax stage.

(4) Abiotic-biotic interactions - are achieved through the constant interplay between living organisms and their environment

or habitat. The presence or absence of resources and the relative use of those resources are limiting factors which determine the overall health of the ecosystem.

Combining the above information about ecological cycles with the knowledge of the systematic nature of the interconnections of components and processes allows the formulation of a general conceptual model of any ecosystem. However, it must be pointed out that humans and their artifacts have begun to seriously affect ecological processes. Originally, primitive human societies existed closely with natural systems and were more strongly influenced by natural laws. Currently, the opposite is true: We have ignored ecological principles and tended to divorce ourselves from being integral components of functioning ecosystems. This has caused (1) ecological degradation and destruction, (2) a loss in our understanding of the intrinsic value of natural ecosystems, and (3) the design of human systems which are not compatible with the environment.

The practical importance of understanding ecosystems is in directing the planning and management of human activities which use and transform ecosystems and their components. To ensure the long-term survival of both human and natural systems, land uses must be planned which combine ecological theory with practical needs. The vast array of land uses have resulted in ecosystems which can be identified by their mix of natural and cultural components, functions, and influences. This mix of influences will likely continue into the future, but it is the responsibility of decision and policy makers to ensure that sufficient opportunities for diverse environments are available into the future.

Odum (1975) defines freedom not as the absence of restraints but as the availability of options. This includes and requires the preservation of as wide a variety of functional environments as possible. He argues that the biggest stumbling blocks to meaningful planning and management of a variety of options is a fragmentation in decision making and in our inability to assess carrying capacity for human populations. An analysis of human population dynamics is not within the scope of this research effort, but it is sufficient to note that wild populations which exceed their carrying capacity usually decrease - sometimes dramatically - until the environment can recover sufficiently to allow resumption of growth. On the other hand, improper decision making leads to inadequate or damaging planning and management efforts. An observation of pollution, urban sprawl, technological overkill, or loss of species diversity indicates that not many decisions were properly made.

The goal of ecologically based land use planning is to renew and maintain ecosystems in as natural a state as possible. A natural ecosystem, as Glikson (1971) points out, is exemplified by its ability to sustain its wild and human populations and in the fact that it is in balance with the environment. Therefore, fully cultural ecosystems (such as urban areas) can be natural if they conform to ecological principles (as advocated by Stearns and Montag, 1974).

Because ecology is based on a complex body of knowledge and is constantly changing as new facts are discovered, it tends to be inaccessible to decision makers. The development of a conceptual framework which presents ecological theory as a basis for planning and management is necessary. Such a framework must act as a communication tool to organize the expertise and ideas of planners, systems analysts, scientists, economists, politicians, engineers, and the public. Since most environmental problems should be solved at the ecosystem level, each person involved with decisions should be oriented on that level. Problems can be solved only when they are examined holistically, and ecosystems are holistic concepts. If questions are asked according to an understandable conceptual framework, there will begin to be a meaningful organization of resources to address the questions.

Planning the use of ecosystems and ecosystem components is an area of human endeavor in which the needs of both natural and human communities must be considered. Planning on the ecosystem level (1) provides an understanding of ecological components, structures, functions, and interconnections proposed by no other approach, and (2) human interactions with the environment can be implemented with a view toward the functioning and maintenance of the living earth as a whole. Ecosystem planning is based on an organized combination of information which is gathered for the identification of the ecological constraints, opportunities, or impacts of land uses. Lands (ecosystems) can then be classified according to their capability and suitability to support desired uses.

Various classification and planning schemes have been proposed in the past twenty years. Among the more important effects are those which have based their methodologies on ecological approaches. Work done by Hills (1961, 1970, 1976), Van der Maarel (1978), McHarg (1969), and Holling (1978) has led to the development of systems which can apply ecological information co-equally with that of other disciplines in the formulation of land use plans. Such planning is a focus of efforts to preserve a variety of ecosystems, to maintain diversity, and enhance resilience to outside perturbations.

The ecosystem plan - whether it is a small project within a particular ecosystem or a planning effort in either a large or small ecosystem - and the management programs which are developed from it must be based on ecological principles, must be an integration of suitable information, and must be holistic to address the complete scope of the problem area. Ecological principles and goals which underlie a management framework include the need to:

(1) work within ecosystem constraints (a functioning ecosystem provides a good measure of environmental quality);

(2) adopt and maintain a long-term carrying capacity approach to resource management in both natural and artificial systems;

(3) prevent irreversible environmental changes; and

(4) protect critical environments and habitats.

In developing the plan or management activity, investigators must organize a monitoring program which continually evaluates the parameters which determine whether any of the above goals have been altered. While there is no need to measure or list everything within an ecosystem, a determination of significant connections _is_ necessary. This will provide an indication of different variables which might be impacted at various locations or times. It will also provide a gradient structure for evaluating relative resilience, variability, and diversity leading to some quantification of carrying capacity and the ability to predict possible environmental disturbances. While carrying capacity is a difficult principle to monitor until it has been exceeded (i.e., the populations have not become extinct), careful protection of habitats will tend to maintain a realistic carrying capacity limit.

Just as for wild populations, there are critical habitats or environments for humans. These include ecosystems used for food production, unique areas valued for their aesthetic or recreational pleasure, lands which act as buffers from natural forces (such as floodplains, beaches, or wetlands), and ecosystems which contain rare or endangered species. While it is important to protect and enhance environments which provide resources necessary for human existence, it is equally important to preserve the diversity and resilience of natural systems for their potential for future benefits.

The conceptual framework for ecosystem planning and management, therefore, is based on adoption of a philosophy which seeks to provide a decision-making path that is least environmentally disruptive and which directs human processes as parts of evolving nature as opposed to intrusions upon it (Garlauskas, 1975). This can be achieved on a long-term basis by (1) promoting the rational use of resources, (2) adopting a conservation ethic, (3) limiting degradational activities, (4) managing the environment to support optimum populations (human, wildlife, and plant) within ecological constraints, and (5) adopting holistic, continuous, and updatable planning and management programs which seek to follow an ecologically sound philosophy.

LIST OF REFERENCES

LIST OF REFERENCES

Ackoff, R. L. 1971. "Towards a System of Systems Concepts." Management Science. Vol. 17.

Andrews, Richard N. L. 1978. "Applications of Environmental Analysis" in Environmental Analysis for Land Use and Site Planning. W. M. Marsh, ed. New York: McGraw-Hill.

Ashby, W. R. 1956. An Introduction to Cybernetics. New York: Wiley.

Avery, Thomas E. 1975. Natural Resource Measurements. New York: McGraw-Hill.

Barlowe, Raleigh. 1972. Land Resource Economics. Englewood Cliffs, New Jersey: Prentice-Hall.

Barlowe, Raleigh, ed. 1976. Protection of Essential Lands. Department of Resource Development, Michigan State University.

Bennett, C. F. 1973. Man and Earth's Ecosystems: An Introduction to the Geography of Human Modification of the Earth. New York: Wiley.

Bertalanffy, L. von. 1928. Kritische Theorie der Formbildung. (Modern Theories of Development). Borntraeger, Berlin; translated by J. H. Woodger. Oxford: Oxford University Press. 1934.

________. 1956. "General Systems Theory." General Systems Yearbook. Vol. I. Society for General Systems Research, Washington, D.C.

________. 1969. General Systems Theory: Foundations, Development, and Applications. New York: Braziller.

Bishop, A. B.; Fullerton, H. H.; Crawford, A. B.; Chambers, M. D.; and McKee, M. 1974. Carrying Capacity in Regional Environmental Management. U.S. EPA-600/5-74-021, Washington, D.C.

Brady, R. F.; Tobias, T.; Eagles, P. F. G.; Ohrner, R.; Micak, J.; Veale, B.; and Dorney, R. S. 1979. "A Typology for the Urban Ecosystem and Its Relationship to Larger Biogeographical Landscape Units." Urban Ecology. 4:11-20.

Brower, J. E. and Zar, J. H. 1977. Field and Laboratory Methods for General Ecology. Dubuque, Iowa: Wm. C. Brown Co.

Cannon, Walter B. 1939. The Wisdom of the Body. New York: W. W. Norton & Co.

Chapman, R. N. 1928. "The Quantitative Analysis of Environmental Factors" in Fundamentals of Ecology. E. P. Odum, 2nd ed. 1959. Philadelphia: W. B. Saunders Co.

Chorley, R. J. 1964. "Geomorphology and General Systems Theory." General Systems Yearbook. Vol. 9. Society for General Systems Research, Washington, D.C.

Collier, B. D.; Cox, G. W.; Johnson, A. W.; and Miller, P. C. 1973. Dynamic Ecology. Englewood Cliffs, New Jersey: Prentice-Hall.

Commoner, Barry. 1970. "The Ecological Facts of Life" in No Deposit - No Return. Man and His Environment: A View Toward Survival. H. D. Johnson, ed. Reading, Massachusetts: Addison-Wesley.

Corliss, J. C.; Pfister, R. W.; Buttery, R. F.; Hall, F. C.; Mueggler, W. F.; On, D.; Phillips, R. W.; Platts, W. S.; and Reid, J. E. 1973. Ecoclass - A Method for Classifying Ecosystems. U.S. Forest Service, Washington, D.C.

Cowles, H. C. 1889. "The Ecological Relations of the Vegetation of the Sand Dunes of Lake Michigan" in Fundamentals of Ecology. E. P. Odum, 2nd ed. 1959. Philadelphia: W. B. Saunders Co.

Dansereau, Pierre. 1978. "An Ecological Grading of Human Settlements." Geoforum. 9:161-210.

Dasmann, R. F. 1975. The Conservation Alternative. New York: Wiley.

________. 1976. Environmental Conservation. New York: Wiley.

Davis, Phillip B. 1979. "An Ecological Approach for Highway Routing in Michigan." Doctoral Dissertation. Michigan State University.

Dorney, R. S. and Hoffman, D. W. 1979. "Development of Landscape Planning Concepts and Management Strategies for an Urbanizing Agricultural Region." Landscape Planning. 6:151-177.

Driscoll, R. S. and Spencer, M. M. 1972. "Multispectral Scanner Imagery for Plant Community Classification." International Symposium on Remote Sensing Environment. Ann Arbor, Michigan, October 1972 Proceedings. 8:1259-1278.

Environmental Protection Agency. 1972. Environmental Assessment for Effective Water Quality Management and Planning. Washington, D.C.

Farness, Sanford S. 1979. Unpublished class notes. Department of Urban Planning and Landscape Architecture. Michigan State University.

Foin, Theodore C. Jr. 1976. Ecological Systems and the Environment. Boston: Houghton-Mifflin.

Food and Agriculture Organization of the United Nations. 1976. "A Framework for Land Evaluation." Soils Bulletin 32, Soil Resource Development and Conservation Service, Land and Water Development Division.

Forbes, S. A. 1887. "The Lake As a Microcosm" in Fundamentals of Ecology. E. P. Odum, 2nd ed. 1959. Philadelphia: W. B. Saunders Co.

Friederichs, L. 1930. "Die Grundfragen and Gesetzmassigkeiten der landund forstroutschafthichen Zoologie" in Fundamentals of Ecology. E. P. Odum, 2nd ed. 1959. Philadelphia: W. B. Saunders Co.

Garlauskas, A. B. 1975. "Conceptual Framework of Environmental Management." Journal of Environmental Management. 3:185-203.

Giles, R. H. Jr. (ed.). 1969. Wildlife Management Techniques. The Wildlife Society, Washington, D.C.

Glikson, Artur. 1971. The Ecological Basis for Planning. The Hague: Martinus Nyhoff.

Goldsmith, F. B. 1975. "The Evaluation of Ecological Resources in the Countryside for Conservation Purposes." Biological Conservation. 8:89-96.

Gotschalk, D. R. and Parker, F. H. 1974. "Carrying Capacity: A Basis for Planning." Department of City and Regional Planning. University of North Carolina, Chapel Hill.

Gotschalk, David R. 1975. "State Growth Management: A Carrying Capacity Policy" in Management and Control of Growth. Vol. III. Randall W. Scott, ed. The Urban Land Institute, Washington, D.C.

Hackett, Brian. 1971. Landscape Planning: An Introduction to Theory and Practice. Newcastle-upon-Tyne, England: Oriel Press Limited.

Harris, J. A. and Williams, D. G. 1975. "The Ecological Basis for Natural Resource Management" in Managing Terrestrial Ecosystems. J. Kikkawa and H. A. Nix, eds. Ecological Society of Australia Proceedings. Brisbane: Watson and Ferguson.

Heffernan, P. 1975. "Environmental Management Tools" in Environmental Impact Assessment. R. Corwin, et. al., eds. San Francisco: Freeman, Cooper.

Helliwell, D. R. 1973. "Priorities and Values in Nature Conservation." Journal of Environmental Management. 1:85-128.

Hills, G. A. 1961. The Ecological Basis for Land Use Planning. Ontario Department of Lands and Forests Research Department No. 46.

________. 1976. "An Integrated, Iterative, Holistic Approach to Ecosystem Classification" in Ecological (Biophysical) Land Classification in Canada. J. Thie and G. Ironside, eds. Lands Directorate, Environment Canada.

Hills, G. A.; Love, D. V.; and Lacate, D. S. 1970. Developing a Better Environment. Ontario Economic Council.

Holdgate, M. W. 1978. "The Application of Ecological Knowledge to Land Use Planning" in The Breakdown and Restoration of Ecosystems. M. W. Holdgate and M. J. Woodman, eds. New York: Plenum Press.

Holling, C. S. 1973. "Resilience and Stability in Ecological Systems." Annual Review of Ecology and Systems. 4:1-23.

________, ed. 1978. Adaptive Environmental Assessment and Management. New York: Wiley.

Holling, C. S. and Clark, W. C. 1975. "Notes Towards a Science of Ecological Management" in Unifying Concepts in Ecology. Report of the Plenary Session of the First International Congress of Ecology. The Hague, September 8-14, 1974. W. H. VanDobben and R. H. Lowe-McConnell, eds. The Hague: Dr. W. Junk B. V.

Holt, S. J. and Talbot, L. M. 1978. New Principles for the Conservation of Wild Living Resources. Wildlife Monograph No. 59. The Wildlife Society, Washington, D.C.

Hopkins, L. D. 1977. "Methods of Generating Land Suitability Maps: A Comparative Evaluation." AIP Journal. October, 1977. pp. 386-400.

Hopkins, Lewis D.; Wood, Bruce R.; Brockmann, Debra; and Messina, Louis. 1973. EIS: A Handbook for Writers and Reviewers. Illinois Institute of Environmental Quality, University of Illinois.

Jacobs, Jurgen. 1975. "Diversity, Stability, and Maturity in Ecosystems Influenced by Human Activities" in Unifying Concepts in Ecology. Report of the Plenary Session of the First International Congress of Ecology. The Hague, September 8-14, 1974. W. H. VanDobben and R. H. Lowe-McConnell, eds. The Hague: Dr. W. Junk B. V.

Jacobsen, N. K. 1978. "The Balance Between Agriculture, Forestry, Urbanization, and Conservation: Optimal Pattern of Land Use" in The Breakdown and Restoration of Ecosystems. M. W. Holdgate and M. J. Woodman, eds. New York: Plenum Press.

Jain, R. K.; Urban, L. V.; and Stacy, G. S. 1977. Environmental Impact Assessment: A New Dimension in Decision Making. New York: Van Nostrand Reinbold.

Klir, George J. 1969. An Approach to General Systems Theory. New York: Van Nostrand Reinbold.

________, ed. 1972. Trends in General Systems Theory. New York: Wiley.

Kramer, N. and deSmit, J. 1977. Systems Thinking: Concepts and Notions. Leiden, Netherlands: Martinus Nyhoff.

Krebs, Charles J. 1972. Ecology: The Experimental Analysis of Distribution and Abundance. New York: Harper and Row.

Laszlo, Ervin. 1972. The Systems View of the World. New York: Braziller.

Leopold, L. B.; Clarke, F. E.; Hanshaw, B. B.; and Balsley, J. R. 1971. A Procedure for Evaluating Environmental Impact. Geological Survey Circular 645. Washington, D.C.

Libby, L. W. and Newman, M. D. 1977. "Land Use Planning and Policy - Michigan in Perspective." Cooperative Extension Service Bulletin E-1061. Michigan State University.

Liebig, Justus. 1840. "Chemistry in Its Application to Agriculture and Physiology" in Fundamentals of Ecology. E. P. Odum, 2nd ed. 1959. Philadelphia: W. B. Saunders Co.

Maarel, E. Van der. 1975. "Man-Made Natural Ecosystems in Environmental Management and Planning" in Unifying Concepts in Ecology. Report of the Plenary Session of the First International Congress of Ecology. The Hague, September 8-14, 1974. W. H. VanDobben and R. H. Lowe-McConnell, eds. The Hague: Dr. W. Junk B. V.

________. 1978. "Ecological Principles for Physical Planning" in The Breakdown and Restoration of Ecosystems. M. W. Holdgate and M. J. Woodman, eds. New York: Plenum Press.

MacArthur, R. H. 1972. Geographical Ecology: Patterns in the Distribution of Species. New York: Harper and Row.

Marsh, William M. 1978. Environmental Analysis for Land Use and Site Planning. New York: McGraw-Hill.

May, R. M. 1978. "Factors Controlling the Stability and Breakdown of Ecosystems" in The Breakdown and Restoration of Ecosystems. M. W. Holdgate and M. J. Woodman, eds. New York: Plenum Press.

McHarg, Ian L. 1969. Design With Nature. Garden City, New York: Natural History Press.

Michigan Department of Natural Resources. 1976. Michigan Land Cover/ Use Classification System. Office of Land Use. State of Michigan.

Miles, Ralph F. 1973. Systems Concepts: Lectures on Contemporary Approaches to Systems. New York: Wiley.

Miller, G. Tyler. 1975. Living in the Environment: Concepts, Problems, and Alternatives. Belmont, California: Wadsworth.

Montana Agricultural Experiment Station. 1979. Natural Resource Inventory Checklist, Section 5 Plant/Animal Ecology. National Science Foundation Research Report #50, Washington, D.C.

Morse, N. H. 1975. "An Environmental Ethic - Its Formulations and Implications." Canadian Environmental Advisory Council Report No. 2.

National Environmental Policy Act of 1969, PL 91-190, U.S. Code, Vol. 42, Secs. 4321-4347 (1970).

Odum, E. P. 1969. "The Strategy of Ecosystem Development." Science. 164:262-270.

________. 1971, 1959. Fundamentals of Ecology. 3rd, 2nd ed. Philadelphia: W. B. Saunders Co.

________. 1975. Ecology. New York: Holt, Reinhart and Winston.

Ovington, J. D. 1975. "Strategies for the Management of Natural and Man-Made Ecosystems" in Unifying Concepts in Ecology. Report of the Plenary Session of the First International Congress of Ecology. The Hague, September 8-14, 1974. W. H. VanDobben and R. H. Lowe-McConnell, eds. The Hague: Dr. W. Junk B. V.

Patten, Bernard C. 1959. "An Introduction to the Cybernetics of the Ecosystem: The Trophic-Dynamic Aspect." Ecology. Vol. 40.

________, ed. 1971-1972. Systems Analysis and Simulation in Ecology. Vol. I-IV. New York. Academic Press.

Pianka, Eric R. 1978. Evolutionary Ecology. New York: Harper and Row.

Rapoport, Anatol. 1972. "The Search for Simplicity" in The Relevance of General Systems Theory: Papers Presented to Ludwig von Bertalanffy on His Seventieth Birthday. Ervin Laszlo, ed. New York: Braziller.

Reichle, D. E. 1975. "Advances in Ecosystem Analysis." Bioscience. 25(4):257-264.

Rodgers, C. Leland and Kerstetter, Rex. E. 1974. The Ecosphere: Organisms, Habitats, and Disturbances. New York: Harper and Row.

Rosen, Robert. 1972. "Some Systems Theoretical Problems in Biology" in The Relevance of General Systems Theory: Papers Presented to Ludwig von Bertalanffy on His Seventieth Birthday. Ervin Laszlo, ed. New York: Braziller.

Rowe, P. G.; Mixon, J.; Smith, B. A.; Blackburn, J. B. Jr.; Callaway, G. L.; and Gevitz, J. L. 1978. Principles for Local Environmental Management. Cambridge, Massachusetts: Ballinger.

Schumacher, E. F. 1973. Small is Beautiful. New York: Harper and Row.

Sewell, Granville H. 1975. Environmental Quality Management. Englewood Cliffs, New Jersey: Prentice-Hall.

Shelford, V. E. 1913. Animal Communities in Temperate America. University of Chicago. Chicago: University of Chicago Press.

Simpson, E. H. 1949. "Measurement of Diversity." Nature. 163:688.

Smith, Robert L. 1980. Ecology and Field Biology. New York: Harper and Row.

Southwick, C. H. 1976. Ecology and the Quality of Our Environment. New York: Van Nostrand.

Stearns, F. J. and Montag, I. 1974. The Urban Ecosystem: A Holistic Approach. Stroudsburg, Pennsylvania: Dowden, Hutchinson and Ross.

Sutton, David B. and Harmon, N. Paul. 1973. Ecology: Selected Concepts. New York: Wiley.

Tansley, A. G. 1935. "The Use and Abuse of Vegetational Concepts and Terms" in Fundamentals of Ecology. E. P. Odum, 2nd ed. 1959. Philadelphia: W. B. Saunders Co.

Thienemann, August. 1939. "Grundzuge einer allgemeineu Oekologie" in Fundamentals of Ecology. E. P. Odum, 2nd ed. 1959. Philadelphia: W. B. Saunders Co.

Thomas, M. R.; Davis, P. B.; and Humphrys, C. R. 1978. Ecological Effects of Highway Construction Upon Michigan Woodlots and Wetlands. Agricultural Experiment Station, Michigan State University.

Tyler, D. B. 1975. "Environmental Science: Perspective and Methods" in Environmental Impact Assessment. R. Corwin, et. al., eds. San Francisco: Freeman, Cooper.

United Nations General Assembly. 1972. Report of the U.N. Conference on the Human Environment. A/CONF. 48/14, 3 July 1972.

Van Dyne, G. M., ed. 1969. The Ecosystem Concept in Natural Resource Management. New York and London: Academic Press.

Vernadsky, W. I. 1944. "Problems in Biochemistry" in Fundamentals of Ecology. E. P. Odum, 2nd ed. 1959. Philadelphia: W. B. Saunders Co.

Watt, K. E. F. 1968. Ecology and Resource Management. New York: McGraw-Hill.

Watt, K. E. F.; Malloy, K. R.; Varshney, C. K.; Weeks, D.; Wirosardjono, S., eds. 1977. The Unsteady State. Honolulu: University of Hawaii Press.

Way, D. S. 1973. Terrain Analysis. Stroudsburg, Pennsylvania: Dowden, Hutchinson, and Ross.

Webster's Third New International Dictionary. 1961. Springfield, Massachusetts: G. and C. Merriam Co.

Weiner, N. 1948. Cybernetics. New York: Wiley.

Whittaker, R. H. 1975. Communities and Ecosystems. New York: MacMillan.

Young, O. R. 1964. "A Survey of General Systems Theory." General Systems Yearbook. Vol. IX. Society for General Systems Research, Washington, D.C.