AN ECOSYSTEM ASSESSMENT TECHNIQUE FOR ENVIRONMENTAL IMPACT STATEMENTS

by

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ABSTRACT

The goal, policies, and procedural methods of the National Environmental Policy Act of 1969 (NEPA) may soon be applied to the planning of general environmental policies, land-use zonings, and program statements. Planning on such a broad scale should consider the substantive portion of NEPA and not merely comply with the procedural portions. A matrix framework is developed through the use of three ecosystem assessment worksheets that relate comprehensive characterizations of ecosystems and impacts to the capacity of the ecosystem to resist structural and functional changes following perturbations. This capacity, or homeostasis, has limits which can be used as a criterion for determining the necessary long-term mitigative commitments of energies and resources that may be required by man's activities. The worksheets present a simple impact ranking scheme that can be used as an aid in land-use zoning or comparison of alternatives. They are compatible with the procedures outlined in NEPA. The worksheets can serve as a guide for compliance with the substantive portions of NEPA and can educate decision makers in the concepts of ecosystem homeostasis.

CHAPTER 1

INTRODUCTION

The National Environmental Policy Act of 1969 (NEPA) (Public Law 91-190, see Appendix) presents a goal and states policies and procedural methods that are intended to alter the decision-making process for all federal actions significantly affecting the environment. The procedural methods are found in Section 102 of NEPA. These have been formalized in the Council on Environmental Quality (1973) guidelines for the preparation of Environmental Impact Statements (EIS). These statements have been the focus of nearly all the controversy and litigation related to NEPA (Anderson, 1973, p. 273). The result is that private consultants (Agardy, 1974; High, 1974; Willis, 1974) and federal officials (Calkins, 1974; Kane, 1974) alike have considered alterations of decision-making procedures to be the major intent of NEPA.

As spokesmen for the Environmental Protection Agency and the Council on Environmental Quality, Calkins and Kane represent the segment of federal government that is responsible for the implementation of NEPA. Although their viewpoint may be narrow, it is the one that may determine the future role of NEPA in federal decision making.

The resulting increased completeness and clarity of decision making have prompted consideration of using the EIS process for overall policy planning. This consideration has been strengthened by the desire to cut down on the number of EIS's required. Standard program statements examining the impacts by types of projects (e.g., all fast-breeder reactors) will contain the complete complement of information and analyses needed for an EIS. Individual project statements will therefore be less detailed, since projects will be compared to the standard program type to see if differences exist that need study or if the project can be exempted from the EIS process as being compatible with the accepted program statement. Another example might be land-use zoning derived from an examination through the EIS process of environmental capabilities that indicate the compatibility of typical projects and environments (Calkins, 1974; Kane, 1974).

The major strength of the EIS process to date has been the alteration of procedural methods within some federal agencies. There are, however, policies set forth in Sections 101 and 102 of NEPA that relate to the goal of harmonious interaction of man and nature. This goal is most relevant at the policy-planning level of government. Progress toward this goal has received little attention, since at the policy-planning level, decision making is truly extraorganizational (Anderson, 1973, p. 292) and is not restricted by the procedural methods prescribed by NEPA. Lindblom's (1968) book describes the gamelike processes that do operate at the policy-planning level. Rather than hoping to impress a completely integrated decision-making methodology on the higher levels of government, it might be most useful to present guides that not only educate the decision maker in the fundamental processes of environmental systems but also increase his ability to choose alternatives by having inputs that related to the policies and goal.

The purpose of this thesis is to examine the relationships between the goal, policies, and procedural methods of NEPA that can serve as guides to planning and decision making. Because the language of NEPA in Section 102 backs away from enforcement of goals (". . . to the fullest extent possible . . . the Federal Government shall . . ."), the guides must be strong enough to serve as a mandate that can overcome this basic deficiency in NEPA. The guides are a set of ecosystem assessment worksheets (EAW), which are validated by meeting the following objectives:

1. EAW's will be in a format that educates the decision maker in the fundamental processes of ecology, guides the early planning stages of broad program statements or land-use zonings, and presents the ecologic activity relationships without overly complex weighting or aggregation schemes, so that the decision maker and all interested parties can analyze the decision. The format will be developed according to the procedural methods of NEPA, while using principles of efficient organizational functions.
2. EAW's will have inputs and outputs that related to the substantive portion of NEPA in a manner usable in the extraorganizational process of federal policy planning.
3. EAW's will be based on studies in theoretical and empirical ecology. Consistent generalizations will be derived that describe the structural and functional characteristics of ecosystems and the responses of ecosystem to perturbations.

4. EAW's should be usable with available techniques of ecologic study.

Objectives 1 and 2 will be discussed in Chapter 2, objective 3 will be discussed in Chapter 3, and objective 4 in Chapter 4.

CHAPTER 2

DECISION MAKING AND GOAL SEEKING UNDER THE NATIONAL ENVIRONMENTAL POLICY ACT

In attempting to alter federal decision making, NEPA employs two tactics: The statement of policies that must be followed and the statement of procedural methods to be used. These tactics have been applied to interagency decision making and will be applied to extra-organizational policy planning in the future. These tactics, as applied at both levels, will be examined to reveal the organizational and political mechanisms they use or modify in achieving altered decision making.

NEPA as a Decision Document

NEPA was intended to correct what can be called organizational and informational pathologies in existing federal environmental planning and decision making. Deutsch (1966, p. 247) defines two major inter-agency pathologies: power, the ability of an agency or individual to attain its objectives consistently; will, the organizational tendency to resist internal rearrangements. Traditionally, power has promoted will. Wilensky (1967, pp. 41-55) defines one major informational pathology as the distortion of information. This distortion, which is promoted by the hierarchical structures that typify federal agencies, can be caused by staff specialists using parochial solutions for problems or geographically localized objectives and by the selective transfer of information to the decision maker.

These organizational and informational pathologies have encouraged decisions that characteristically accept existing policies that may be narrow in scope. These are the incremental decisions that are likely to be made by decision makers lacking confidence in the available information (Bradley, 1973), while working in a framework of continually changing political leaders and policies (Brock et al., 1973, p. 14; Wilensky, 1967, p. 21) and officially constrictive bounds on possible actions (Deutsch, 1966, p. 62). Such decisions may become rather automatic (Carpenter, 1971) with no examination of alternatives or consequences (Bradley, 1973). From the viewpoint of self-preservation of the organization, this tactic reduces the risk of embarrassing errors by maintaining rigid and repetitive interaction of policies and personnel (Brock et al., 1973, p. 32), while keeping the lag time between decisions and results to a level within the response capabilities of the organization (Deutsch, 1966, p. 65). Required responses have usually been incremental adjustments of policy to accommodate the occasionally unforeseen results (Bradley, 1973; Brock et al., 1973, p. 14) or pleas that the consequences are outside the bounds of possible organizational actions (Deutsch, 1966, p. 62). Agencies adept in these skills develop the pathologies of power and will.

Section 102 of NEPA and subsequent Council of Environmental Quality guidelines (Council of Environmental Quality, 1973) have altered organizational will be specifying a decision process that can be strictly enforced by the courts (Anderson, 1973, p. 12). Certain steps in that process have eliminated some of the pathologies. Section 102(2)(A) demands the use of interdisciplinary approaches to planning and decision making. Section 102(2)(D) demands the development and comparison of alternatives to the proposed action.

The use of teams of interdisciplinary specialists is a standard cure for informational and organizational pathologies. Discussion of opposing viewpoints should help illuminate hidden parochialisms and promote concensus, provided the decision maker can keep track of the arguments (Wilensky, 1967, pp. 46-55). The extrastructural position of interdisciplinary teams has reduced some of the hierarchical pathologies related to communication blocks (Wilensky, 1967, p. 43), while creating new pathologies related to information overload (Wilensky, 1967, p. 41) and increased lag time (Deutsch, 1966, p. 65).

The EIS process, as defined by numerous court decisions, should involve the full disclosure of all available information and discussion of all viable alternatives in all stages of planning (Anderson, 1973, pp. 21, 179). Completeness of information and recognition of possible outcomes are the basis for rational decision systems (Bradley, 1973) that resolve a problem with one final decision eliminating two incremental decisions concerning selection of information and construction of alternatives before the final decision (Brock et al., 1973, p. 5). Generation of complete information requires very large intercisciplinary teams, either as staff or as outside consultants. The lag time is almost doubled on some types of projects (Greene, 1974). Faced with thousands of pages of information and technical opinions over a period of years, the decision maker can easily lose track of the arguments and can therefore lose the fundamental condition for successful planning (Wilensky, 1967, p. 54). Decisions can become dominated by professional ideologies and debates over best solutions that substitute for continual examination of the problem itself (Wilensky, 1967, p. 80; Brock et al., 1973, p. 19). The appointment of middlemen with optimal information-responsibility ratios is a sound counter to this tendency (Deutsch, 1966, p. 156). However, the fear of litigation over procedural compliance with NEPA has caused decision makes to place lawyers in this middleman position (Anderson, 1973, p. 288). It is doubtful that their legal analyses induce harmony between technological solutions and problem goals.

The information overload and increased lag time that the NEPA helped create have produced a second round of solutions. These primarily involve the use of matrix checklists that reduce some of the informational overload and improve the decision maker's ability to oversee the interdisciplinary planning process. In general, columns of activities and rows of environmental characteristics are displayed in chart form, with each cell in the column-row matrix representing a possible impact category. Staff members fill in the cells with measures of impact magnitude that are usually weighted values derived from the relative importance and duration of the impact, occasionally including a subjective probability of occurrence (Schlesinger and Daetz, 1973). The cell values can be combined and reduced further until one or a few numbers are left to represent the total impact of various alternatives. Information overload is reduced considerably. The decision maker can merely compare a few numbers to arrive at a decision. He can refer to the disaggregated cell values to spot probable impacts that might have particular significance to his constituents or opponents. If he is moderately perceptive, he can determine the biases and parochialisms of his staff by examining the weighting scheme and the row and column assignments. For example, an engineer might not include wildlife breeding grounds in his row of environmental characteristics or he may give their destruction a low value; a naturalist might consider several breeding grounds separately and give them high value. Overseeing capabilities are thus improved. Lag time can be shortened if matrices are used in early planning stages. If impacts are clearly displayed, initial comments and replanning or rejection of particular alternatives can be made before extensive data collection and analyses are performed.

Another approach to coping with information overload has been the application of systems analysis. Since the NEPA states that the government shall "utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences . . . ," Section 102(2) (A), and ". . . develop methods . . . which will insure that presently unquantified environmental amenities and values may be given appropriate consideration . . . ," Section 102(2)(B), it has occasionally been assumed that Congress meant for these concepts to be treated with the simultaneous, numerical methods of systems analysis. The compatible format that certain methodologies demand if trade-offs between environmental and social values are to be made (Dee et al., 1972) restricts the consideration of grossly unusual exceptions and solutions. This is primarily the result of disaggregates that exclude synergistic relationships (Dee et al., 1972, p. 120), failures of the method to account for long-term consequences (Fischer and Davies, 1973; Schlesinger and Daetz, 1973), and the integral construction of method and objectives (Hoos, 1972, p. 8). The last problem is the most dangerous at the policy level, since it can lead to automatic decisions that can lack careful conceptualization of the problem (Hoos, 1972, p. 8) or, worse, precede conceptualization (Wilensky, 1967, p. 82). A methodology that was constructed to integrate and resolve the ecologic and socioeconomic aspects of irrigation projects might preclude the possible alternatives of water-rights transfers or elimination of agriculture. Systems analysis can also reintroduce the problem of concealment or loss of information within the analysis.

The alterations discussed so far have applied to internal agency decision making. Section 102(2)(C) demands review and comments by other agencies, which must be incorporated into further planning. This tactic is based on an extraorganizational, political method of correcting informational pathologies caused by the broader, overriding constraints of agency doctrine, tradition, and constituency pressures. This method uses what Lindblom (1968, pp. 28-42) calls rules of power play. The cooperation between agency and legislative decision makers has been based on long-standing hierarchies and degrees of power. These structures are, in turn, based on strong agency doctrines and influential constituencies. Conflicts between strong agencies had to be resolved by compromises or exchange of favors, while conflicts with weak agencies could be largely ignored. Section 102(2)(C) uses these structures but changes the rule to reduce the power discrepancies. What could have resulted was a more extensive "pork barrel" of projects passed around in response to favorable or noncritical comments on EIS's. Again, the courts' strict interpretation of the commenting procedure has demanded critical detailed evaluations of EIS's and evidence that comments have been considered (Anderson, 1973, pp. 224-228).

The procedural methods of NEPA have produced alterations in decision making that are significant but partial. Methodology, while consuming the most time and effort, is the least important part of the decision process. Information that has been clarified, distilled, and condensed must still be related to goals and policies before decisions can be made. This part of the decision process is the most important (Wilensky, 1967, pp. 3, 60, 82; Brock et al., 1973, p. 34) and has seen little improvement since the implementation of NEPA.

NEPA as a Goal-seeking Guide

The substantive sections of NEPA are clear. Section 101(a) states that federal actions will promote the general welfare and encourage harmonious interrelationships between man and nature for present and future generations. It is perhaps cynical to suppose that this goal is ignored, since it is considered as only a slight modification of the "apple pie and motherhood" goals that are so fundamental to the American system as to be the expected outcome of any well-planned policy. The ignoring of the more explicit definitions of the NEPA policies of Section 101(b), as pointed out by Anderson (1973, pp. 265, 273), supports this supposition.

Section 102(2) establishes the policies and procedural methods needed to achieve the goal of Section 101. The stated policies are consideration of "the relationships between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity," Section 102(2)(C)(iv), "any irreversible and irretrievable commitments of resources," Section 102(2)(C)(v), and technology and economics, Section 102(2)(B). There is an obvious lack of understanding of the relative importance of these policies. The courts have not decided if economic analyses should be included as part of an EIS (Anderson, 1973, p. 254). The courts have completely confounded the issue of long-term versus short-term uses of resources by ruling that alternatives considered, as demanded by Section 102(2)(C)(iii), must be implementable in the same time span (Anderson, 1973, p. 221). They have placed great emphasis on balancing environmental and social considerations without any suggestion on how it should be done (Anderson, 1973, pp. 256-258).

The problem of considering long-range consequences is further aggravated by the short-range benefits that support existing power plays at the policy-making level (Lindblom, 1968, p. 42), where NEPA's substantive sections are most important. A mandate that relates the policies to the goal must be concrete enough to provide rules that will be followed in the bargaining over values at the higher levels of government. The rules should be based on logical valid theories that relate environmental processes to the practicalities of the political-engineering system (Slobodkin, 1968). More significantly, if they do not promote a continuing progress toward the ideal of man's omnipotence, they may be eventually rejected (Ackoff and Emery, 1972). This last criterion of a successful mandate is a misinterpretation of man's relative position in the total environment.

The most fundamental concept in ecology must be introduced at this point in order to set the framework for this thesis. That concept is evolution as presented in Evolution in Changing Environments by Levins (1968). Man must be reminded that he is an animal that evolved in response to certain environmental parameters. He is, like all other species, uniquely adapted for a given range of parameters and is poorly adapted outside that range. Figure 1 illustrates the result of two fundamentally different evolutionary development schemes. Fitness is defined as a species' ability to optimize its growth and reproduction. The species must respond to a range of environmental variables, both biotic and abiotic. Species that adapt phenotypically by specializing internal functions and external morphology can have a high fitness but within a narrow range of environmental variability. Species that can invade and rapidly dominate a suitable environment but can exist only marginally in less suitable areas are either colonials or pests. Species that adapt genotypically by generalizing internal function and external morphology are persistent and have a great tolerance to a wide range of environmental variability but can never have high fitness in any given environment. They balance their inability to optimize by resisting environmental fluctuations that eliminate phenotypically adapted species. Their fitness curves are lower and broader. It is difficult to assign a fitness curve to man. He exhibits the phenotypic adaptive trait of a narrow tolerance to environmental variables; yet he has a very low fitness by the usual means of high birth and growth rates. Biologically, man may have the shaded fitness curve shown on Figure 1.

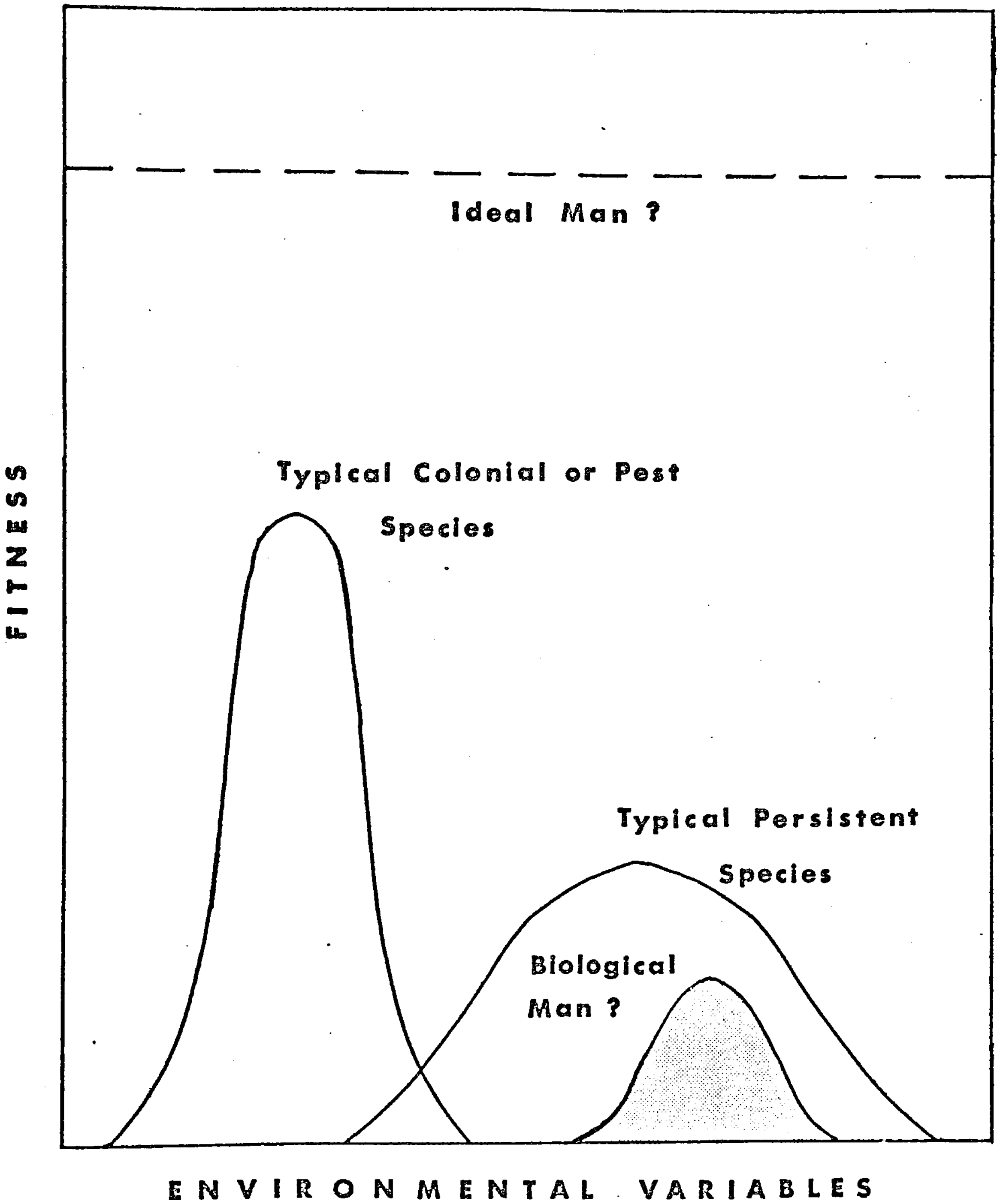

Figure 1. Fitness Curves for Man and Other Species

The area under a species' fitness curve is constant and depends on the amount of energy available to the organism that can be devoted either to increased fitness or increased tolerance. Man's unique ability to control energy flows has allowed him to protect himself from environmental variables or to modify them, thus increasing his fitness and tolerance. Evolution is a process that rewards the species that makes full use of any genetic change that is advantageous for adaption.

There are those (Eckbo, 1969, p. 26; McHarg, 1969, pp. 26-29) who believe that man has turned his innate abilities to modify the environment to his advantage into an obsession to dominate the world, with goals and objectives facilitating the most efficient exploitation of the widest possible range of environments. Man's end state would then look like the dashed fitness curve in Figure 1. Is this the ideal of omnipotence that Ackoff and Emery (1972) recommend? Is this ideal possible?

A large proportion of the criteria for goals and policies that Ackoff and Emery say will promote omnipotence are found in NEPA: The complete distribution of maximally broad use of goods and services through the future (Section 101); the efficient choice among alternatives based on scientific research, technology and education, Section 102 (2) (A,B,F), and the ability to sacrifice present values for future values Section 101 (b)(1), Section 102(2)(C)(iv,v). These could be interpreted as leading toward human domination were it not for the recurring references to the future of the environment. To the extent that man is supporting an expanded fitness curve by taking energy from exhaustible sources, exploiting (i.e., subtracting area from a fitness curve) other species to near extinction and relying on protective structures made from exhaustible mineral resources, his omnipotence is evolutionarily ephemeral. Would not a more comforting and therefore more acceptable ideal be based on man's immortaility as an evolving unit? The author believes this ideal is attainable, if man can learn to take maximum advantage of renewable environmental processes and develop technologies of energy utilization that are not tied to exhaustible sources.

A successful mandate requires that man find the characteristics of the environment that assess its potentional long-range usefulness. According to Slobodkin's (1968) criterion, the characteristics must also relate to the political-engineering system.

One environmental characteristic is homeostasis. Collier et al. (1973, p. 491) define it as the capacity of the environment to maintain its structure and function in the face of perturbations. It is the result of the environment's renewable, cyclic, and long-term (over geologic time) processes. Within the limits of an ecosystem's homeostasis, man's modifications to structural or trophic relationships can be compensated by automatic responses by the ecosystem itself (e.g., by shifting energy flow rates or populations). Outside the limits of homeostasis, modifications by man cause imbalances that can lead to significant permanent changes in the ecosystem, such as species extinction. If man is to avoid producing ecosystems dominated by his activities, he must assume the tasks of mitigating those aspects of his activities that exceed the homeostasis of the ecosystem and of maintaining the perturbed, imbalanced ecosystems. These tasks consume energy and materials in addition to those required for the activities. In the terms of a political-engineering system such use of resources may be considered wasteful, inefficient, and generally undesirable but may be required to prevent changes to the ecosystem. Essentially the homeostasis of an ecosystem is inversely proportional to the mitigative commitments that may necessarily accompany certain of man's activities.

The mandate in the substantive sections of NEPA is that man's approach to total success will be enhanced by using the limits of homeostasis of an ecosystem as a criterion for determining the necessary long-term mitigative commitments of energies and resources required by his activities. Relating this mandate to political power play introduces a paradox. A decision maker whose only function is to procure resources and commit them to activities will find less value in a criterion based on homeostasis for mitigative commitments than will a decision maker whose function is the conservation of resources that are continually under attack by those who consider them as a usable surplus. The power plays that could follow the acceptance of the NEPA's mandate are difficult to predict. Decision makers could adapt to the rules of the mandate with tactics ranging from decisions not to build potentially disruptive projects to comprehensive, rigid land-use plans that specify all possible activity-environment combinations. Since assessment of a value will only develop after it has been accepted and used for some time, it is believed that homeostasis should be initially related to mitigative commitments. The value of resources in discrete uses is perhaps a more familiar concept to decision makers than their value as a part of an integrated ecosystem.

The acceptance and implementation of this mandate will depend on its expression in a framework that can be used in the modified decision-making process that was discussed in the first part of this chapter. The framework should be simple and general enough to supply insights into activity-environment relationships in initial or preplan-stages. It should have enough substance to guide agency specialists and interdisciplinary teams in further planning and should allow condensation of information without concealment.

The generalizations that relate homeostasis and mitigative commitments to man's activities will be developed in Chapter 3. Generalized ecosystem characteristics, subject to the constraints on their assessment discussed in Chapter 4, will be arranged in the ecosystem assessment worksheet framework in Chapter 5.

CHAPTER 3

ECOCYSTEM ECOLOGY

Consistent generalizations describing the primary structural and functional characteristics that contribute to ecosystem homeostasis and the most basic types of perturbations that can affect homeostatic responses are not stated explicitly in ecological literature. Models describing complex ecosystem interactions and experiments dealing with specific ecosystem components or relationships were surveyed to discover recurring parameters, constraints, and cause-effect relationships. These aspects of the literature had to be aggregated into broad structural and functional characteristics before any generalizations emerged. In the first half of this chapter, these characteristics are described.

The discovery of predictable trends in responses of generalized ecosystem characteristics to various perturbations and their effect on homeostasis was only possible after a significant disaggregation of all ecosystems into five classes. These classes are defined by fundamentally different evolutionary pressures that result in ecosystems with unique response patterns. These classes and the general types of perturbations are introduced implicitly in the discussion of ecosystem characteristics. Their relationship to homeostatic responses are described in the second part of this chapter.

Species Diversity and Productivity

Two of the most studied ecosystem characteristics have been species diversity and productivity. In this thesis, the words "diverse" and "diversity" will be used in describing the variety and uniformity of the occurrence of the components of a system. Species diversity is commonly measured by the Shannon-Weiner diversity index (Sanders, 1968),

$$H = -\sum P_i \log_2 P_i$$

where P_i = the probability of sampling the i^{th} species. This index is used in information theory to quantify the potential information capacity of a signal. In ecology, it quantifies the potential structural complexity of a community. A highly diverse community contains small populations of many species. The probability of sampling a particular species is low, since individual samples drawn from the community are likely to contain nonrepetitive assortments of species (Wilhm and Dorris, 1968). As probabilities decrease, the value of H increases. A low-diversity community is dominated by a few species, whose populations can be high or low. The probability of sampling a particular species repeatedly is high, and samples are repetitive. Increased probability reduces H.

A species diversity index helps define the successional stages of a community by quantifying such a fundamental ecosystem characteristic as potential structural complexity. In low-maturity, or "pioneer," stages, species diversity is low. The community is dominated by colonial species, such as grasses, that can invade newly created or harsh environments. As the community reaches an intermediate maturity, colonials occur along with more persistent species, like trees, that can withstand occasional extreme stresses. This mixture of species types produces the highest species diversity. In late maturity, the community loses some species diversity as the persistent species begin to dominate or force out colonials. References supporting this summary of trends in species diversity are numerous and will be cited individually as this chapter proceeds.

Since a species diversity index is affected either by a change in population or species composition, it is a sensitive indicator of altered community structure. A pollutant that kills individuals of one or many species or affects the success of a species at any time in its life cycle will cause a change in community structure detectable as a lowered species diversity index (Wilhm and Dorris, 1968; Borowitzka, 1972). As the pollutant becomes less effective with time or distance, the community regains its structure. A species diversity recovery curve can be characteristic and predict both the speed of recovery and the type of pollutant even without knowledge of its exact identity or function, i.e., within the broad categories of toxins and energy (organic nutrient or heat) enrichment (Cairns et al., 1971; Borowitzka, 1972; Woodwell, 1971).

For the purpose of planning and decision making, the mechanisms that contribute to species diversity as well as their relationship to homeostasis should be known. The primary mechanism is evolutionary development of greater or lesser number of species in response to climatic variability.

Evolutionary response involves two developmental schemes: phenotype adaptation, leading to greater speciation with high fitness, or genotypic adaptation, leading to lesser speciation with high species tolerance (a broad fitness curve over a range of climatic variables, see Figure 1) (Levins, 1968, pp. 11-13; Sanders, 1968). The response is constrained by the amount of energy available to the organism for either internal regulation or increased production. In relatively constant and uniform (slight or moderate and predictable fluctuations) climates, little energy must be devoted to internal regulation by the organism. Excess energy can be devoted to reproduction and enlarged gene pools resulting in speciation. In uncertain and extreme climates, a large part of the available energy must be devoted to internal regulation not only for the normal wide range of climatic variation but also for the extended extreme variations that occasionally occur. Less energy is available for speciation than for maintenance of a broad genotype in a few species (Levins, 1968, pp. 11, 30; Collier et al., 1973, p. 532).

The above theory is partially supported by older theories that relate energy to productivity and species diversity. These theories (Whittaker, 1953; MacArthur, 1955; Patten, 1959) state that in thermodynamically open biological systems, entropy can be defined as that part of total energy that is required for species and community respiration; excess energy, or negentropy, can be stored by production of biomass. The theories furthermore propose that entropy is the force increasing disorder and negentropy is the force increasing information. An ecosystem with moderate excess negentropy may gain information by increasing species or community complexity (species diversity). A fairly simple relationship appears to exist between species diversity and negentropy, which may be expressed either as the difference between productivity and respiration or their ratio.

Empirical evidence indicates that productivity-respiration ratios do not necessarily correlate with species diversity (Ewing and Dorris, 1970); productivity can have reciprocal functional relationships with other parts of a community in different environments (Riley, 1962) and neither productivity nor respiration have any major relationship to many species once a complex ecosystem has evolved (Fretwell, 1972, p. 60). This lack of generality is to be expected. Respiration is only one part of internal regulation. Current theories joining energy to information (Gatlin, 1972, pp. 191-203) state that the relationships that exist can only be explained by complex extensions from classical thermodynamics into the field of probability theory. Basically, a species diversity index is a measure of the total biotic energy and depends on respiration and productivity and their relationships to efficiencies of information coding, storage, and transmission. These efficiencies increase with genetic complexity. However, the diversity of the ecosystem depends on the expression of genetic complexity by either phenotypic or genotypic developmental schemes. The variety of paths that energy can follow through a developing ecosystem indicates that effects of changing energy flows on productivity and species diversity are not predictable. The interrelationships between species diversity, productivity, energy, and developmental schemes need to be place in a framework that allows consistent generalities in each subdivision that relate to homeostasis.

Ecosystem Classes and Habitat

Four ecosystem classes were introduced in the discussion of developmental schemes. These classes include the different ranges and patterns of climatic variability: constant, uniform, uncertain, and extreme. Reasonably, one can expect the greatest similarities between ecosystems whose structures and functions evolved with similar developmental schemes in response to similar climatic parameters (Holling, 1972). Within each class, the ecosystems should respond to the constraints of energy availability with similar patterns of species diversity, productivity, and succession to maturity. These patterns should involve the presence of indicator species whose life cycles are consistent with the developmental mechanism and constraints.

An additional constraint to evolutionary development is habitat, the topography of the space that the species of an ecosystem must inhabit. It includes both biotic and abiotic structures and the spatial and temporal arrangements of these structures, as well as their effect on energy availability and flows. The habitat characteristics that describe the development and maintenance of ecosystem structure and function are continuity, diversity, periodicity, biogeochemical cycles, and size.

Habitat Continuity and Diversity

The evolutionary role of habitat diversity is important in classifying ecosystems according to homeostasis, as will be shown. The role of habitat continuity in ecosystem maintenance is more relevant to impact assessment and is easier to conceptualize initially.

If an ecosystem is perturbed, recovery may depend on reinvasion by individuals of species that had been displaced by direct changes in species composition (e.g., harvesting) or by toxins (Cairns et al., 1971). Recovery may also depend on the renewal of energy flows that had been disrupted (Collier et al., 1973, p. 443; Woodwell, 1971). If the perturbed area of an ecosystem is continuous with unperturbed areas, recovery will be enhanced (Cairns, Lanza, and Parker, 1972; Holling, 1972), and the continuity is defined as high. An ecosystem with low continuity has physical barriers isolating the perturbed area from unperturbed sources of replacement species or energy, and rapid recovery is impeded. A slow recovery through a succession of stages may not be possible with low continuity. It depends on the evolutionary development of habitat diversity, which is constrained by the historical nature of the habitat continuity.

Both biotic and abiotic components of a habitat contribute to its diversity. Habitat diversity, like species diversity, describes the complexity of the ecosystem. However, since it involves the entire topography of the system (i.e., includes species diversity), it is a much more difficult characteristic to quantify. This difficulty has been partially overcome in limited circumstances (e.g., foliage-height diversity equals $-\sum P_i \log_2 P_i$ where P_i = probability of sampling the i^{th} height class of vegetation, a parameter that relates to bird ecology (MacArthur and Wilson, 1967, p. 110)), but is generally described qualitatively. A quantitative ranking of low, medium, and high for diversity will suffice for the following discussion.

The diversity of the abiotic environment is the initial driving force for evolutionary development. The phenotypic adaptation and speciation promoted by low diversity in climatic variability increase ecosystem biotic structural and functional diversity (species diversity, and complex energy flow patterns). As the ecosystem matures, continuity with adjacent habitats allows continued exchange of colonial, dispersive species (MacArthur and Wilson, 1967, p. 21; Fretwell, 1972, p. 79). These species may have evolutionary differences resulting from particular geologic patterns within the same climate. The moderate genotype that allows colonial species to adapt to slightly different habitats is lost when the ever-increasing biotic diversity creates an increasingly complex topography in which a species can optimize phenotypically (Levins, 1968, p. 103).

A high-maturity ecosystem that has evolved in a low-diversity abiotic environment can still develop an extraordinarily high habitat diversity. It is, however, a diversity dominated by biological complexity (Sanders, 1968) characterized by species with strong abilities to optimize in a narrow range of biotic and abiotic variability. The habitat continuity that provides a rich mix of species for the developing ecosystems loses importance in mature ecosystems that contain a large inventory of opportunistic species.

The development of ecosystems in high-diversity or extreme climates is more complex, since it can involve not only genotypic (introduced as the generality on p. 20) but also phenotypic adaptation depending on the habitat diversity and continuity. Again, continuity is a vital force in dispersing species. However, in climates with high-diversity or extreme variability, species with moderate genotypic adaptive abilities are at a disadvantage when operating at the fringe of slightly different contiguous habitats. Species that can adapt to new geologic and biologic habitat components while surviving the greatest climatic variability evolved into what are called colonial and pest species. They balance the energy requirements of broad genotypes and high reproductive capacities by short life cycles and organismic simplicity (Murphy, 1968) and can even withstand the destructive effects of ionizing radiation (Woodwell, 1971). These species are typical of low-maturity ecosystems. Their success in the harshest of abiotic habitats allows the phenotypic development of more complex organisms by modifying the ecosystem by reducing climatic variability (Collier et al., 1973, pp. 113-116, 513; MacArthur and Wilson, 1967, pp. 49-52). Reduction in abiotic habitat diversity is balanced by increased biotic diversity due to the evolutionary trend toward conversion of abiotic to biotic information. Organismic and energy-flow complexity may be characterized by numerous predator-prey interactions. Rapid shifts to phenotypically different communities can occur along abiotic gradients (Daubenmire, 1956, 1966; Levins, 1968, p. 75). These shifts are evidence of the fact that organisms can adapt to combinations of fluctuating variables that together reduce total habitat diversity (e.g., if coincident temperatures times humidities equal a constant value) (Fretwell, 1972, p. 80). Species diversity reaches its highest level in medium-maturity ecosystems, where the sum of abiotic and biotic components of habitat diversity is highest, allowing colonial species and multiple competing predators to coexist with species characterizing the next successive stage of high maturity (Collier et al., 1973, p. 515; Holling, 1972). Species in the last stages of succession evolved by a developmental scheme that reduced variability in energy flows through increased efficiency. The simplest of these persistent species are characterized by slow growth, long life, and sufficient environmental resistance to insure successful reproduction with low fecundity (Murphy, 1968; Collier et al., 1973, p. 516). Other species optimize the available energy through complex behavioral traits, such as territorialism and migration (Fretwell, 1972, pp. 82, 160) and efficient predation (Rosenzweig, 1971; Holling, 1972). The general reduction in habitat diversity caused by these species results in a reduction in species diversity (Fretwell, 1972, p. 160). The structures of extreme and uncertain ecosystems have a wide range of biotic and abiotic habitat components. This makes the importance of various ecosystem characteristics ambiguous and increases the probability of inconsistencies. One exception to the usually beneficial nature of high habitat continuity in ecosystem maintenance occurs if such continuity exists in ecosystems with low species and habitat diversities allowing the spread of pest species (Collier et al., 1973, pp. 244, 534) or domination by the more highly dispersive colonial species (Grime, 1973).

Habitat Periodicity and Biogeochemical Cycles

Species are able to reduce abiotic uncertainty by evolutionary adaptation not only to abiotic habitat components but also to periodic variations of the components. Adaptation to diurnal and annual day-night cycles is pervasive. Temperature cycles together with day length are extremely important to species that must exist in climates with high variability since they determine seasonality, thus reducing uncertainty (Pianka, 1967; Patrick, 1968; Ketchum, 1971). Fretwell (1972) devotes an entire book to the influence of seasonal cycles on territorial and migratory species. Both internal regulation and external community functions can be dependent to some degree on periodic signals (Levins, 1968, p. 108); however, the ability to respond to these signals is often lost under stress conditions, such as starvation (Ivlev, 1961, pp. 283-284).

Periodic cycles can be found in the flow of nutrients through the ecosystem. Some nutrient flows are affected by their geologic sources, chemical conversions, and biological transport. If these biogeochemical cycles contain periodicities, species may adapt to them. The daily tidal flux of nutrients over benthic communities (Ryther, 1962) or the multi-year cycles of nutrient assimilation and release in extreme ecosystems (Collier et al., 1973; pp. 500-502) can be responded to by species adaptation. The patterns of biogeochemical cycles, even if not periodic, are important. Ecosystems that have adapted to accommodate to certain flow rates and patterns of nutrient availability can become unbalanced by gross changes in flow rates or patterns. If the nutrient flow is greatly increased, the resulting overproductivity by one biotic component of the ecosystem can cause the failure of other biotic components (Rosenzweig, 1971, 1972). A net loss of nutrients can occur if there are open paths to outside sinks for the decomposed unusable overproduction or if some species are displaced outside the system. Open cycles are characteristic of low-maturity ecosystems (Collier et al., 1973, p. 512) and most aquatic systems. On the other hand, ecosystems with open biogeochemical cycles due to large available pools of raw nutrients may be able to recover quickly from energy reduction due to removal of species by harvesting or toxins (Woodwell, 1971). As ecosystems mature, biogeochemical cycles begin to close with increasing retention of nutrients in biomass of deep lake sediments and increasing specialization of species in nutrient recycling activities (Collier et al., 1973, pp. 433, 443, 456, 502).

Habitat Size

The final characteristic of the habitat is its size. This characteristic reveals little generality in cause-effect relationships. It can be important in low- and medium-maturity ecosystems by including enough variables to allow survival of species adapted to dispersion (Mertz, 1971), since it is related to abiotic habitat diversity in these ecosystems. In high-maturity ecosystems, size is effective through components of biotic habitat diversity causing unpredictable results. Territorial, migratory, and predator-prey species have population dynamics that are density dependent but can respond either positively or negatively to a given change in habitat size, depending on the species (Fretwell, 1972, p. 8; Collier et al., 1973, pp. 181-191).

It is appropriate to introduce a fifth ecosystem class following this discussion of habitat: the transitional ecosystem class. The area of contact between markedly different habitats is the transition zone. Although transitional ecosystems share some characteristics with the adjacent habitats, the magnitude of the characteristics of the transitional ecosystem depend on the difference in magnitude of the characteristics in the adjacent habitats.

Homeostasis of the Ecosystem Classes

In order to construct a framework for ecosystem assessments, disaggregations are necessary. Ecosystems can be divided into five classes: extreme, constant, uniform, uncertain, and transitional. Each class can be categorized by its characteristics of species diversity, indicator species, productivity, and habitat, including climate.

The most general types of perturbations or impact categories that have been mentioned in the discussion of ecosystem characteristics are changes in species composition, energy flow, habitat, and the addition of toxins. Changes in species composition can be effected by addition or removal of species or altered distributions in time or space. Energy flow, defined in its broadest sense, includes both radiant and thermal budgets and the nutrients that are converted into biomass. Since habitat is defined by the interaction between all biotic and abiotic components, any change in these components is a change in habitat. Toxins include any substance that disrupts the structure and function of the ecosystem.

The homeostasis of the five ecosystem classes will be discussed in relation to the four impact categories.

Extreme Ecosystems

The ecosystems with the least homeostasis have evolved under conditions of extreme or harsh fluctuations in the physical environment. Species in arid or arctic ecosystems devote their genotypic adaptation to resistance to abiotic stress. They are sensitive to changes in the biotic habitat caused by any of the impact categories (Sanders, 1968).

Low metabolism and slow chemical reactions caused by low temperatures or lack of water result in slow biogeochemical cycles that are often dependent on rapid periodic releases of nutrient pools. Species whose populations oscillate over a large amplitude are typical of extreme environments (May, 1971, 1972; Collier et al., 1973, p. 500). Collier et al. (1973, p. 502) present two examples . In the extreme ecosystem of the arctic, the nutritional value of the vegetation can become very low when a significant portion of the limited soil nutrients becomes tied up in large lemming populations. When this occurs, mortality of the lemmings becomes high and fecundity low, resulting in a rapid population reduction. Decomposition of the dead lemmings returns the nutrients to the soil, and the resulting improvement in the nutritional quality of the vegetation initiates a new cycle of lemming population. In an arid ecosystem, fire can initiate a similar disruption in population cycles by rapidly releasing the nutrients bound up in the slow-growing shrubs, trees, and cacti. Fast-growing colonial grasses and wildflowers dominate for a time until the persistent species regain dominance through their tolerance to the annual extremes of climatic variables.

Species with inordinate resistance survive the alternating submersion and dessication and abrasive mechanical agitation of the intertidal zones. Unlike arid or arctic ecosystems, the intertidal ecosystem has large energy resources from solar radiation and continually replenished nutrient supplies (an open biogeochemical cycle). Phenotypic adaptation under these conditions produces species that can potentially dominate the habitat unless controlled by competition or predation (Paine, 1966). Changes in the balance between competition and predation causes a reduction in species diversity. An example is the condition known to mariners as fouling, the complete take-over of habitat surfaces by barnacles or algae.

Periodicities of diurnal, tidal, or seasonal cycles provide cures that help species to coordinate activities with environmental changes. Increasing day lengths and temperatures trigger reproductive activities that can be successful only in the short arctic summer. Decreasing day length and temperature trigger dormancy and hibernation that assure survival through the winter. Continuance of periodicities is critical (Pianka, 1967).

Constant Ecosystems

Constant ecosystems also have low homeostasis. The conditions and mechanisms responsible for sensitivity to perturbations are exactly the opposite of those of extreme ecosystems. Extensive phenotypic adaptation produces extremely complex trophic webs composed of species with low genotypic resistance to abnormal conditions. Any perturbation that disrupts the normal narrow range of biotic and abiotic parameters may cause a rapid collapse of ecosystem structure (May, 1971, 1972). The rapid recycling of nutrients within the biotic components of closed biogeochemical cycles makes tropical ecosystems susceptible to nutrient deficiencies if a large percentage of the biomass is removed or destroyed over a short period of time (Woodwell, 1971; Collier et al., 1973, p. 523). A complete regression to low-maturity colonials, like bamboo, initiates recovery of the ecosystem structure. This process is made extremely slow by the deficiency of nutrients and the natural lack of climatic variability that could give advantages to a wide variety of species. The habitat diversity must be re-created through vegetative succession over many years. The homeostasis of the open ocean is largely unknown. It is postulated that constant abiotic conditions and low nutrient source have produced species that are intricately related biologically to solar radiation and primary production. Impacts that reduce primary production may destory the ecosystem functionally. Periodicities other than day-night cycles and day length should be of minor importance in these biologically controlled ecosystems. Reducing habitat size should not have much effect on the closely interacting constant ecosystem unless there are wide-ranging predators or migrating species present.

Uniform Ecosystems

Ecosystems with mild and predictable or controlled climatic fluctuations generally have low homeostasis. Littoral ecosystems and man-controlled agricultural systems make up this class. The moderation of climatic extremes and the low to medium habitat diversity that occur in ponds and lakes promote development of species with few genotypic adaptations. Initially, the low energy resources in low maturity oligotrophic lakes limit the phenotypic tendency to optimize growth and reproduction. A gradual increase in species diversity and productivity in medium-maturity mesotrophic lakes is the response to increasing energy. As energy inputs increase, early successional species respond by increasing productivity. Their domination of nutrient pools eliminates species less adapted for rapid growth and reproduction. Rapid additions of energy or pest species to oligotrophic and mesotrophic lakes are hard to restrict because of the high continuity and open geochemical cycles that can produce rapid succession to eutrophic conditions. Once eutrophic conditions are reached, the ecosystem becomes very homeostatic. The low-oxygen conditions prevent major changes in species composition. Increased energy can be accommodated by the dominant algae, while decreased energy can be accommodated by anaerobic decomposition of dying algae. A high resistance to toxins also maintains organisms in eutrophic lake ecosystems. The presence of insects as a major component of the lake ecosystem contributes to homeostasis. The sheer numbers of species, each with peculiar adaptive traits and multiple-form life cycles make insects very resistant to biotic and abiotic perturbations (Fretwell, 1972, p. 30), but the dependency of insects on photoperiodicity and thermoperiodicity is a weak link in lake homeostasis.

Man's propensity for reducing natural variability for the sake of increased production or easier maintenance has produced some of the least homeostatic ecosystems in the world (Holling, 1972). Occasionally, attempts are made to promote the growth of a particular species by giving it optimal conditions of energy and habitat. However, some of these species, such as trout and shellfish, are minor components of their natural ecosystems. Optimizing conditions for growth may be ineffectual for those species having broad genotypes and lacking the evolutionary ability to optimize (Sander, 1968) or may seriously disrupt the remaining ecosystem (Cairns et al., 1971). The reduced ecosystem variability may instead favor competive endemic species (Mertz, 1971;

Grime, 1973) or foreign pest species that can optimize in the controlled conditions. This latter result is encouraged in large-scale agricultural whose large size and low species and habitat diversities reduce populations of predators that could respond to an invasion of pests (Collier et al., 1973, p. 534).

Uncertain Ecosystems

Uncertain ecosystems achieve the highest level of homeostasis. The presence of many species with broad genotypic adaptations allows the ecosystem to absorb changes in species composition and energy and habitat without major structural and functional changes. Here homeostasis is directly proportional to the level of species and habitat diversities, unlike the inversely porportional relationship between homeostasis and species and habitat diversities that occurs in constant ecosystems. The existence of biotic or abiotic habitat discontinuities is significant. Where these exist, increased abiotic continuity or any other habitat modifications may result in one ecosystem being invaded by tenacious species from an adjacent ecosystem (Collier et al., 1973, p. 352; MacArthur and Wilson, 1967, p. 115). The high level of interaction within and between the biotic and abiotic components of uncertain ecosystems makes the exact prediction of the results of any of the impacts on size, periodicity, and biogeochemical cycles difficult. In general, they should be moderate up to a point, beyond which the effects are unknown. This break point may depend to a large degree on the particular species present.

Transitional Ecosystems

The same cautions that must be exercised in managing uncertain ecosystems with high homeostasis applies to managing transitional ecosystems. Transitional ecosystems exhibit characteristics of high habitat continuity and open biogeochemical cycles, broad genotypic colonial species, and medium species and habitat diversities that contribute to high homeostasis. Moreover, they are particularly dependent on these characteristics. The continuing flow of species and nutrients is critical, since this flow is a substitute for the evolution of a complete complement of perculiarly adapted species. Those that have adapted to specific transitional ecosystems have existed over the necessary length of time to become highly dependent on periodicities transitional to those of the adjacent ecosystems. In an estuarine environment these periodicities may include temperature and nutrient cycles and seasonal species interactions (Patrick, 1968; Ketchum, 1971), which are coordinated with the salinity gradients that move up and down the estuaries producing increased fresh-water ecosystem characteristics during spring floods and increased salt-water ecosystem characteristics during summer droughts. MacArthur and Wilson's (1967) book on island biogeography reveals similar complexities in these transition zones. The homeostasis of transition zones is highly variable and depends on the maintenance of critical ecosystem characteristics.

The search for generalizations and trends that relate ecosystem characteristics and responses to homeostasis produces four major divisions that will be used in the analytical framework of the ecosystem assessment worksheets to be introduced in Chapter 5. These divisions are ecosystem classes, ecosystem characteristics, studies required to classify ecosystems, and impact categories. Applications of the worksheets is based on classification studies and impact assessments. The practical accomplishment of this basis is considered in Chapter 4.

CHAPTER 4

PRACTICAL CONSIDERATIONS

The successful application of the ecosystem assessment worksheets (EAW) to decision making depends on the validity of the analytical framework that was developed in Chapter 3 (ecosystem classes, ecosystem characteristics, studies for classification, and impact categories). The ecological models used in the development of the framework will be discussed in the first part of this chapter. In the assessment of impacts based on theory or models, any lack of specificity should be compensated by assuming a worst-case response. Presently available measurements and indices can help planners replace worst-case assumptions with known effects and threshold values (McAllister, LeBrasseur, and Parsons, 1972). The techniques may also be useful in assessing the homeostasis of ecosystems of each class. These techniques will be discussed in the second part of this chapter.

Ecologic Models

Many ecologic models and the EAW's are based on the same theoretical foundation; therefore, the preliminary insights gained from the models should apply to the EAW's. Eventually, the EAW's could be overshadowed by completed models, which are generally models of compartment systems with disaggragated biotic and abiotic processes linked by parameter flow rates (Jeffers, 1973).

Table 1 illustrates the number of parameters that may be required for ecologic models. Holling and Ewing (1971) actually use about fifteen more parameters. Necessary simplifications are commonly made. Stochastic models are usually involved in the detailed study of simple closed subsystems, such as studies of the plant-aphid-parasite system or fish feeding experiments, while deterministic models are used for the study of large open systems. Deterministic models use integrated community parameters, such as population and habitat distribution, in place of the disaggregates of the stochastic models. The stochastic model may appear to have the greater validity, except for the fact that the mathematical relationships must be obtained from data gathered over a wide range of possible values in order to supply enough information for curve fitting. Naturally derived data over a wide range are available for ecosystems, such as lakes, that have been disturbed through harvesting, artifical enrichment, or poisoning (Rosenzweig, 1971).

A somewhat easier approach is the use of standard statistical distributions that generate parameter values. This approach supposedly accounts for individual genetic variation (Labeyrie, 1971; Holling and Ewing, 1971; Mertz, 1971; May, 1973). However, these models have been criticized as being unrealistic in allowing half an organism or impossible densities (Gilpin, 1972) or producing extinction at moderately low populations (May, 1972; Jeffers, 1973), and for always being worst-case solutions (Gilbert and Hughes, 1971). A very disturbing experiment by Etter (1971) showed that Holling's models produce similar results whether run stochastically or randomly.

Table 1. Ecological Model Parameters

Model Parameters	Stochastic					Deterministic		
	Griffiths and Holling, 1969; Holling, 1972	May, 1971, 1972, 1973	Ivlev, 1961	Mertz, 1971	Rosenzweig, 1971, 1972	Fretwell, 1972	Levins, 1968	MacArthur, 1955
Web Structure	X	X	X					X
Web Flow Rates	X	X	X		X	X		X
Biomass	X	X	X		X		X	
Population	X	X	X	X	X	X	X	X
Growth Rates	X	X	X	X	X	X	X	X
Time Lags	X	X			X			
Predator Saturation	X	X	X		X			
Density-dependent Fecundity	X		X		X	X		
Limiting Nutrients		X			X			
Behavior (unspecified)					X			X
Predator Switching		X[a]						
Rate of Successful Search	X							
Exposure Time of Prey	X							
Handling Time by Predator	X							
Hunger or Starvation	X		X					
Learning	X					X		
Inhibition	X							
Territorial or Migratory						X		

a. Murdoch (1969)

The deterministic models of Table 1 produce insights that are probably as valid as the stochastic subsystems of Holling if both are extrapolated to whole ecosystems. At this time, all the models place organisms in restricted, single, trophic roles which may be unrealistic (Fager, 1962; May, 1973).

Until the artifacts of randomization are removed from stochastic models or sufficient data are obtain to validate deterministic models, the only generalization that can be deduced from theoretical ecology are those chosen for the EAW framework. Indeed, there is a broad support for the belief that interecosystem extrapolations cannot be made (May, 1971; Fretwell, 1972, p. 167; Collier et al., 1973, p. 511), although typical curves of population dynamics may indicate when ecosystems are functionally similar (Woodwell, 1971; Holling, 1972; Fretwell, 1972, p. 75).

The potential value of ecologic models may never be greater than for the production of consistent insights into general structural and functional processes. That alone is significant. The construction of completely operational computer models that behave exactly like ecosystems may never be realized. As Milsum (1966, p. 391) points out, biological systems produce signals whose variance due to external parameters is very close to the variances produced by natural random occurrences in the ecosystem itself and therefore predictions of cause-effect relationships cannot be conclusive. Presently available measurements and indices will have to provide characterizations and impact assessments for specific ecosystems if the generalized results from ecologic models are not sufficient for decisions.

Assessment of Ecosystem Characteristics and Impacts

The importance of competent staff ecologists and physical scientists is illuminated in the following discussion of specific assessment techniques. An enormous amount of judgment is needing in choosing methodologies and analyzing results (Dee et al., 1972, p. 2; Fischer and Davies, 1973; Agardy, 1974). Since ecosystem maturity depends on the relationships of all ecosystem characteristics, its assessment by experts in the initial planning stages can direct studies toward the most critical characteristics and relationships. For example, a search for early successional species should be made in high-maturity ecosystems to determine if the system can recycle when persistent species are removed (Loucks, 1970).

Species Diversity

The great importance of species diversity in describing ecosystems has been established. Its quantification by the Shannon-Weiner index has been supported theoretically. This index produces sample values that correlate well within similar physical environments and are independent of sample size. Other diversity indices based on the log of species densities have poor correlation and are dependent on sample size (Sanders, 1968). The Battelle method for Environmental Impact Statements uses the latter type index (Dee et al., 1972, p. 34).

There are several major problems in the assessment of species diversity. The identification of species (aquatic insects, in particular) is often based on very limited taxonomic studies using fine morphology (thus, the various human races would be classified as separate species) with the use of keys containing dicotomies that experts find difficult to discern. The sequential comparison index is a substitute for species-based indices and is no more invalidated than they by the "splitters and lumpers" of classical taxonomy (Cairns and Dickson, 1971; Cairns et al., 1972). This index is based on the patterns found if organisms are spread over a grid and differentiated by gross morphological differences. Determinations of ecosystem complexity by biologists and non-biologist using this method have produced results that are statistically identical with a 95% confidence. This method may have value in its simplicity and be accurate enough for placement of certain ecosystems within classes. Obviously, the system must have species that can be collected and brought to a laboratory for random distribution over a grid. In certain riparian and littoral benthic communities, the families Chironomidae (midges) and Elmidae (elmid beetles) cannot be subdivided macroscopically, although the families are morphologically different. Since these families may represent over a hundred species with large populations, it is clear why the sequential comparison index would be in appropriate.

Another problem with species diversity indices are their sensitivity to fluctuations in both species composition and population. While this sensitivity is useful in monitoring quality of environment and detecting pollutants, it does complicate the assessment of ecosystem characteristics. Indices can be greatly affected by seasonal occurrences, such as emergence of aquatic insects and migrations. An ecosystem should be characterized by its low, high, or average annual diversity. An average annual diversity would probably be best for a general ecosystem placement, with a knowledge of seasonal patterns being very important to the assessment of various impacts and their timing.

The last problem is the coice of the part of the ecosystem to be studied for species diversity characterization. The necessity for simplification is the result of both taxonomic and logistic difficulties. The taxonomic difficulties have been discussed. Possible logistic problems include difficulties of sampling certain species, such as bacteria and protozoa, that change populations between field and laboratory and whose identities are lost with preservation; the differences in collection and identification methods and equipment needed for various classes of organisms; possible destruction of habitat by sampling methods; and a possible need to coordinate the assessment studies with monitoring programs. The choice of the part of the ecosystem should be based on ecologically acceptable principles. Subwebs that contain a complete trophic complement (producers, consumers, predators, and decomposers) and transfer little energy to other ecosystem components may be sufficiently representative (Paine, 1956). Groups of organisms that may be the most relevant for ecosystem characterization are those, such as trees and shrubs, whose species diversity reflects the maturity of the ecosystem (Loucks, 1970) or those containing species, such as aquatic insect larvae, with complex annual life cycles and wide-ranging tolerances to various impacts (Cairns and Dickson, 1971).

Indicator Species

Indicator species are categorized according to broad evolutionary similarities indicative of ecosystem classes and successional stage.

Within each ecosystem there can exist particular groups of species whose presence provide an assessment of the ecosystem status and possible response to impacts. If sufficient data exist, species with specialized phenotypes can be used to trace transitions in perturbed ecosystems (Rawson, 1956; Davis, 1964). Trends of transitions can be used to predict impact effects from similar perturbations in natural ecosystems. Certain species can reveal habitat components that may be undetectable by physical methods (Johnson and Briton, 1962; Collier et al., 1973, p. 166). Species that are extremely sensitive to toxins can be identified and their reactions in a perturbed ecosystem predicted without extensive investigation of physiological cause-effect relationships for each activity (Wilhm and Dorris, 1968; Jenkins, 1971; Thomas, Goldstein, and Willcox, 1973). Occurrence of known pest species in an ecosystem should provoke studies of their responses in perturbed environments (Grime, 1973). Care must be taken not to confuse endemic species having broad genotypic tolerance to impacts with foreign pests characterized by rapid dispersion, high fecundity, and competitive dominance, since the former are usually ubiquitous and only predominate if certain species are removed (Gaufin and Tarzwell, 1956; Cairns and Dickson, 1971); whereas, the latter may have to be actively suppressed.

Productivity

Two problems are associated with a productivity assessment: what to measure and how to do it. Most work has involved primary productivity in plants, probably because it is relatively easy to obtain data and because plants are a major producing component of most ecosystems. Precision, accuracy, and generality have been elusive, due mostly to the artificiality and operator dependence of respiration chambers (Steeman Nielsen, 1962; Collier et al., 1973, p. 424) and wide natural variations resulting from complex interactions between productivity and temperature, light, wind currents, and feeding pressure by herbivores (Fager, 1962; Riley, 1962; Ewing and Dorris, 1970). Since ecosystem functions are dependent on energy flow rates as well as instantaneous quantities, multiple determinations must be integrated over a given time to be of value in characterizing ecosystem productivity. When individual primary productivity determinations have large variations, the resulting integrated value is practically useless as a basis for extrapolating the higher trophic levels (Fager, 1962). Secondary (herbivorous) productivity assessments suffer from the same error sources plus errors produced by behavioral modification of metabolism. A biomass accumulation ratio (total biomass/gross primary production) may be the best measurement of ecosystem productivity (Collier et al., 1973, pp. 492, 515). Use of the ratio eliminates the errors due to respiration measurements and integrates energy flows by assessing the amount that is concentrated as biomass. It also relates to ecosystem maturity and species diversity since it is sensitive to the different productivities of colonial and persistent plant and animal species.

Habitat

Since habitat includes all biotic and abiotic components of the ecosystem, the assessment of its characteristics is subject not only to the problems discussed above but also to those that occur in the abiotic components. Macrometeorological records of the National Weather

Service, which include average temperature and precipitation distributions over hundreds of square miles, can be used to classify ecosystems. Mesometeorological and micrometeorological records are needed for habitat characterization. Mesometeorological phenomena, such as drainage winds, heat islands, and periodicities, may be discernible from the National Weather Service data or may be known by local inhabitants. Otherwise, the years of record needed for confident prediction make climatic studies unfeasible at the planning stage. Thirty to fifty years of record are required to predict local rainfall patterns; five times the cycle frequency (e.g., five years for annual cycles) are required to describe periodicities (Munn, 1970, pp. 139-143). Micrometeorological studies of air, soil, and water-temperature profiles, wind, diffusion currents, and evapotranspiration require extensive and intensive sampling. Although these studies may be within the time and budget constraints of a planning program, they may be of minimal value in habitat characterization, since species can respond to abiotic habitat interactions that cannot be detected by disaggregated physical measurements. Behavioral patterns of territorial, migratory, and predator-prey species must be known to determine the sufficient size for a habitat (Collier et al., 1973, p. 181). Gross trends or sharp discontinuities in productivity measurements (Johnson and Briton, 1962; Steeman Nielsen, 1962; Riley, 1962) and species diversity indices (Daubenmire, 1966) help determine the continuity and diversity of the habitat. Mass balance studies using existing agricultural or geological soil surveys and water-quality records can indicate the open or closed nature of the biogeochemical cycles. Prediction of impacts and effects must be based on more complete knowledge of mechanisms in both the biotic and abiotic portions of the habitat. The physicochemical characterization of sediments (Lenhard, Ross, and duPlooy, 1962) should be coupled with a reconnaissance for hazardous materials to determine if alteration of the sedimentation processes will produce significant impacts (Van Donsel and Geldreich, 1971). The unusual importance of certain species in nutrient transport (Thomas, 1969) must be known if a change in species composition is anticipated.

The characterization of ecosystems and impacts is a complex problem. Available literature in theoretical and empirical ecology can describe general interactions and response mechanisms and provide a base for cautious, preliminary judgments concerning the nature and magnitude of impacts and the homeostasis of particular ecosystems. For policy planning or land-use zoning, a lack of detail may be acceptable. When specific activities and alternatives are proposed, comprehensive studies should be done. The studies discussed in this chapter should provide the most information for the least effort, since they relate directly to ecosystem homeostasis and mitigative commitments, the recommended base for decisions.

CHAPTER 5

THE ECOSYSTEM ASSESSMENT WORKSHEETS

Requirements for effective policy planning and assessments of ecosystem characteristics will be combined through the five ecosystem classes, nine ecosystem characteristics, four studies for classification, and four impact categories arranged in a three-page matrix format, called the ecosystem assessment worksheets (EAW) (Figures 2-4).

In order to provide some quantification to the assessment of homeostasis, a scale from 1 to 5 was selected to correspond to the concept of increasing orders, or degrees, of consequences that may result from an impact. Ecosystems with high homeostasis should be able to absorb perturbations without significant structural and functional modifications or loss of homeostasis. A response that is within the homeostasis of an ecosystem is called a first-order consequence. In ecosystems with lower homeostasis, a perturbation in one ecosystem characteristic, such as increased productivity, has a higher probability of causing a change in the ecosystem that affects a second characteristic, such as species diversity. This response is a second-order consequence in an ecosystem in which an alteration of structure and function means a possible loss of homeostasis. Second-order consequences are possible, but less likely, in class 1 ecosystems, where perturbations must be larger to exceed homeostasis.

ECOSYSTEM CLASS \ STUDIES FOR CLASSIFICATION	CLIMATIC	NON-CLIMATIC — HABITAT	BIOTA	PRODUCTIVITY	ECOSYSTEM CHARACTERISTICS		HOMEOSTASIS → / ← MITIGATIVE COMMITMENT: Possible System Failure 1	High Order Consequences 2	High Order Consequences 3	High Order Consequences 4	First Order Consequences 5
UNCERTAIN Temperate terrestrial Riparian			X		Species Diversity				L	M	H
			X		Maturity				L	H	M
				X	Productivity				H	L	M
	X	X	X	X	Continuity	Habitat			L-H	L-H	L-H
	X	X	X	X	Diversity	Habitat			M	M	H
	X	X	X		Periodicity	Habitat			+	+	+
		X	X		Biogeochemical	Habitat			O	C	O
			X		Size	Habitat			+	+	N
			X		Indicator Species				Co,M,	Pe,T, M,Pr	Pe,T, Co
TRANSITIONAL Estuarine Insular	Temperature, Precipitation, Wind	Land and Hydrologic Surveys, Foliage Height Diversity	Species Diversity, Indicator Species	Primary or Secondary Productivity, Biomass Accumulation Ratio	Species Diversity			L	M		H
					Maturity			L	M		H
					Productivity			H	H		M
					Continuity	Habitat	L	H	H		H
					Diversity	Habitat		L-H	L-H		L-H
					Periodicity	Habitat	+	+	+		+
					Biogeochemical	Habitat	C	O	O		O
					Size	Habitat		+	+		N
					Indicator Species			Co,M, Pr	Co,M, Pr		Co,Pe, Pr
UNIFORM Littoral Agricultural					Species Diversity		L	M	M/H		L
					Maturity		L	M-H	L/H		H
					Productivity		L/H	M	M		H
					Continuity	Habitat	H	H	H		N
					Diversity	Habitat	L	M	M		N
					Periodicity	Habitat	+	+	+		N
					Biogeochemical	Habitat	O	O	O		O
					Size	Habitat	+	+	+		N
					Indicator Species		Co,P	Co,P, Pe	Co,P, Pe		Co,P
CONSTANT Tropical Oceanic					Species Diversity		H	M	L		
					Maturity		H	M	L		
					Productivity		H	M	L		
					Continuity	Habitat	N	N	N		
					Diversity	Habitat	H	M	L		
					Periodicity	Habitat	N				
					Biogeochemical	Habitat	C	O-C	O		
					Size	Habitat	N				
					Indicator Species		Co,P,T, Pe,Pr	Co,P,T, Pr,M	Co,P Pr,M		
EXTREME Arctic Desert Intertidal					Species Diversity		L H	M			
					Maturity		L M/H	L/H			
					Productivity		L M	H			
					Continuity	Habitat	L H	L-H			
					Diversity	Habitat	L H	H			
					Periodicity	Habitat	+ +	+			
					Biogeochemical	Habitat	C C	O			
					Size	Habitat	+ +	+			
					Indicator Species		Os,Pr, Co,P	Co,P, Pr			

<u>L</u>ow, <u>M</u>edium, <u>H</u>igh <u>O</u>pen, <u>C</u>losed + = Significant, N = Not Significant
<u>Co</u>lonial, <u>Pe</u>rsistent, <u>P</u>ests, <u>Pr</u>edator-Prey, <u>T</u>erritorial, <u>M</u>igratory, <u>Os</u>cillating Population
– indicates a continuum, / indicates distinct levels
Blanks indicate unknown relationships

Figure 2. Ecosystem Assessment Worksheet I

HOMEOSTASIS →

← MITIGATIVE COMMITMENT

ECOSYSTEM CLASS	Ecosystem	Δ SPECIES COMP.	Δ ENERGY	Δ HABITAT	PERSISTENT	NON-PERSIST.	ECOSYSTEM CHARACTERISTICS		Possible System Failure 1	High Order Consequences 2	High Order Consequences 3	4	First Order Conse- quences 5
UNCERTAIN	Grassland	X	Z	Z	X	X	Species Diversity				L		H
	Mixed Hardwoods/						Maturity				L		M
	Riparian		X	Z	Z	Z	Productivity				H		M
			X	X			Continuity	Habitat			H		H
		X	Z	X	X	X	Diversity	Habitat			M		H
			X	X			Periodicity	Habitat			+		+
		X	Z	X	X		Biogeochemical	Habitat			O		O
				X			Size	Habitat			+		N
							Indicator Species				Annual grasses		Hardwood, Stonefly
TRANSITIONAL	Island	All					Species Diversity						H
		Possible					Maturity						M
		First					Productivity						M
		Order					Continuity	Habitat					H
		X					Diversity	Habitat					M
		and					Periodicity	Habitat					+
		High					Biogeochemical	Habitat					O
		Order					Size	Habitat					N
		Z Conse-					Indicator Species						Marsh grasses
UNIFORM	Oligotrophic Lake	quences					Species Diversity		L	M			
	Pine Plantation						Maturity		L	H			
							Productivity		L	M			
							Continuity	Habitat	H	H			
							Diversity	Habitat	L	M			
							Periodicity	Habitat	+	N			
							Biogeochemical	Habitat	O	O			
							Size	Habitat	N	N			
							Indicator Species		Pike	White pine			
CONSTANT							Species Diversity						
							Maturity						
							Productivity						
							Continuity	Habitat					
							Diversity	Habitat					
							Periodicity	Habitat					
							Biogeochemical	Habitat					
							Size	Habitat					
							Indicator Species						
EXTREME							Species Diversity						
							Maturity						
							Productivity						
							Continuity	Habitat					
							Diversity	Habitat					
							Periodicity	Habitat					
							Biogeochemical	Habitat					
							Size	Habitat					
							Indicator Species						

STATUS: "Complete" or "Area X needs further studies to characterize its species diversity. These studies will take about two months."

Δ means "change in"

Figure 3. Ecosystem Assessment Worksheet II

ECOSYSTEM CLASS	Ecosystem	ECOSYSTEM CHARACTERISTICS	IMPACT CATAGORIES: Δ SPECIES COMPOSITION	Δ ENERGY	Δ HABITAT	PERSISTENT TOXINS	NON-PERSISTENT TOXINS	STUDIES NEEDED Man-months: Ecosystem Impact	Life History	Food Web	Web Flow Rates	Pop. Dynamics	Nutrient Web	Behavior	Toxicology	Literature Available
UNCERTAIN	M.H-wood/Riparian	Species Diversity	1x3 = 3	1x3 = 3	1x3 = 3	1x5 = 5	1x3 = 3									
		Productivity	1x3 = 3	1x3 = 3	1x3 = 3	1x5 = 5										
		Habitat: Continuity		1x0.5= 0.5	1x0.5= 0.5											
		Habitat: Diversity	1x3 = 3	1x3 = 3	1x3 = 3	1x5 = 5	1x3 = 3									
		Habitat: Periodicity		1x3 = 3	1x3 = 3											
		Habitat: Biogeochemical	1x3 = 3	1x3 = 3	1x3 = 3	1x5 = 5										
		Habitat: Size			1x0 = 0											
		IMPACT	12	15.5	15.5	20	9	72.0								
UNCERTAIN	Grassland	Species Diversity	3x5 =15	3x5 =15	3x5 =15	3x5 =15	3x5 =15									
		Productivity	3x5 =15	3x5 =15	3x5 =15	3x5 =15	3x5 =15									
		Habitat: Continuity		3x1.5= 4.5	3x1.5= 4.5											
		Habitat: Diversity	3x5 =15	3x5 =15	3x5 =15	3x5 =15	3x5 =15									
		Habitat: Periodicity		3x5 =15	3x5 =15											
		Habitat: Biogeochemical	3x5 =15	3x5 =15	3x5 =15	3x5 =15										
		Habitat: Size			3x5 =15											
		IMPACT	60	79.5	94.5	60	45	339.0								
TRANSITIONAL	Island	Species Diversity	1x4 = 4	1x4 = 4	1x4 = 4	1x5 = 5	1x4 = 4									
		Productivity	1x4 = 4	1x4 = 4	1x4 = 4	1x5 = 5	1x4 = 4									
		Habitat: Continuity		1x5 = 5	1x5 = 5											
		Habitat: Diversity	1x0.5= 0.5	1x0.5= 0.5	1x0.5= 0.5	1x5 = 5	1x0.5= 0.5									
		Habitat: Periodicity		1x5 = 5	1x5 = 5											
		Habitat: Biogeochemical	1x5 = 5	1x5 = 5	1x5 = 5	1x5 = 5										
		Habitat: Size			1x0 = 0											
		IMPACT	13.5	23.5	23.5	20	8.5	89.0								
UNIFORM	Pine Plantation	Species Diversity	4x5 =20	4x5 =20	4x5 =20	4x5 =20	4x5 =20									
		Productivity	4x5 =20	4x5 =20	4x5 =20	4x5 =20	4x5 =20									
		Habitat: Continuity		4x5 =20	4x5 =20											
		Habitat: Diversity	4x5 =20	4x5 =20	4x5 =20	4x5 =20	4x5 =20									
		Habitat: Periodicity		4x0 = 0	4x0 = 0											
		Habitat: Biogeochemical	4x5 =20	4x5 =20	4x5 =20	4x5 =20										
		Habitat: Size			4x0 = 0											
		IMPACT	80	100	100	80	60	420.0								
UNIFORM	Oligo. Lake	Species Diversity	25	25	25	25	25									
		Productivity	25	25	25	25	25									
		Habitat: Continuity		25	25											
		Habitat: Diversity	25	25	25	25	25									
		Habitat: Periodicity		25	25											
		Habitat: Biogeochemical	25	25	25	25										
		Habitat: Size			25											
		IMPACT	100	150	175	100	75	600.0								
Δ means "change in"					TOTAL ALTERNATIVE #		IMPACT =	1520.0								
							TOTAL STUDY TIME =									

Figure 4. Ecosystem Assessment Worksheet III

As the orders of consequences increase in number and complexity, a threshold may be reached beyond which the ecosystem collapses by losing its characteristic structure and function. This occurs in class 5 ecosystems (possible system failure). The high order consequences (classes 2-4) represent the continuum between the two extremes. Without complete ecosystem models, it is impossible to predict the order of consequences that could occur.

It is important to note that current interest in second-order consequences by federal officials (Calkins, 1974; Kane, 1974) does not refer to ecological relationships. These officials are concerned with the environmental impacts of secondary responses resulting from an activity, e.g., increased air pollution from driving to a new shopping center. They apparently do not appreciate the orders of consequences that a perturbation can cause in an ecosystem. This dismal view is reflected by a consultant's comment that he has never been asked or required to assess for current impact statements the long-term impacts of an activity containing continuing mitigative commitments (Willis, 1974).

A ranking scheme using homeostasis class numbers was developed to help guide the decision maker in his choice of policies, zoning plans, and alternative activities. Such schemes are in great demand by decision makers (Calkins, 1974; High, 1974; Kane, 1974).

EAW-I

EAW-I (Figure 2) is educational. It shows the whole range of generalized ecosystems on the homeostasis—mitigative commitment scale in the five ecosystem classes. Within each class, there is a range of ecosystem homeostasis that covers the naturally occuring successional stages from low to high maturity. All the evolutionary developmental schemes and homeostatic response mechanisms discussed in Chapter 3 are considered in the placement of ecosystems. Careful study of the EAW-I reveals the opposing relationships between species diversity and homeostasis and productivity that occur between uncertain and constant ecosystems. It indicates the low homeostasis of all extreme ecosystems and (by a slight modification of format) the peculiar sensitivity of transition zones to reduced periodicities, low habitat continuity, and closed biogeochemical cycles. The characteristic indicator species is represented by the most general classification of organisms by genus type. It indicates what kinds of studies are needed for classification to pinpoint an ecosystem according to the nine ecosystem characteristics.

At this time, the author cannot suggest how the rating of low to high species diversity and productivity should be assigned to available assessment measurements in each ecosystem class. Should a Shannon-Weiner diversity index of 3 be high in uncertain ecosystems and low in constant ecosystems, or medium in both? The low to high ratings as indicated are relative to the range of values that are possible within each ecosystem class. Already perturbed ecosystems may not exactly match the sets of ecosystem characteristics listed on EAW-I. Should a medium-maturity, high-diversity, mixed hardwood forest in an uncertain environment that has had its habitat continuity reduced be placed in homeostasis class 1 or 2? The first problem may be avoided for EAW-I. A catalog placing known ecosystems in their proper position could be compiled by leading ecologists and published in the <u>Federal</u>

Register. As use of the EAW's progresses, this catalog will be expanded and modified as specific ecosystems are studied in greater detail. The second problem resulting from already perturbed ecosystems can be accommodated on EAW-II (Figure 3).

EAW-II

EAW-II indicates those ecosystems that occupy the planning area. These may be placed, using the catalog or by additional studies for classification as typified in EAW-I and as specified under the heading "Status" on EAW-II. The placement of ecosystems can be adjusted to reflect the degree of perturbation that may have affected the natural homeostasis of the ecosystem. EAW-II indicates the first- and n^{th}-order consequences for all possible impacts that are defined as impact categories X ecosystem characteristics. A capital X indicates a matrix cell located where a column (impact category) and row (ecosystem characteristic) intersect. Impacts to indicator species are accounted for in the species diversity, habitat diversity, and biogeochemical characteristics. The genus types listed on EAW-I are replaced by common names of indicator species on EAW-II to help decision makers recognize the ecosystems. Maturity is a characteristic that is dependent on all the other characteristics and therefore does not receive a distinct impact.

An ecosystem homeostasis catalog or a competent ecologist is needed to use EAW-I and EAW-II. The decision maker cannot be expected to solve the problems of ecosystem placement (or assess impacts, as described below), but he should be able to understand the signifance of the homeostasis class numbers, on EAW-II, of the ecosystems for which he is responsible. He should consider each ecosystem according to its homeostasis class number and its relationship in the possible range of homeostasis classes within each ecosystem class. The information presented in this thesis should provide the basis for this understanding.

EAW-III

The use of EAW-III (Figure 4), which is used for zoning and policy planning or ranking of alternatives, requires specialists. These specialists should include biologists and physical scientists having a knowledge of the ecosystems to be studied. They may be staff or experts who may have a more complete knowledge of peculiar habitat relations. A category describing the types of studies needed for a complete analysis of impacts and the time required for them is added to aid the decision maker in making an estimate of the investment needed for planning. He may discover that alternatives equally acceptable environmentally require vastly different planning efforts.

If a decision maker understands the following ranking scheme, he can identify and predict the potential for impacts and their magnitude. These impacts are clearly stated for consideration by the decision maker and interested parties. Unusually high or low, or consistently moderate, impact magnitudes should provoke further investigation to make certain that the numbers are ecologically valid and not the result of staff bias.

The ranking scheme is constructed to relate decreasing homeostasis to the probability of increasing orders of consequences. The rules are arbitrary, so that they produce an approximate geometric progression of potential impact magnitudes as ecosystems go from high to low homeostasis.

Implementation of the EAW-III

Ranking for zoning and policy planning is calculated as follows:

1. All possible impacts listed on EAW-II are considered.
2. The potential magnitude of an impact = (homeostasis class of present ecosystem) x (homeostasis class of ecosystem that may result from the impact).

   Rule A. Impacts cause a shift to the ecosystem farthest to the left in its class, as appears on EAW-I.

   Rule B. If the ecosystem is presently the farthest to the left, the shift is to class 5 (possible system failure).

   Rule C. Certain impacts, such as change in habitat X habitat continuity in transition zones, may be extreme. Potential impact magnitude = (present homeostasis class) x 5.

   Rule D. Certain impacts, such as any impact category X habitat continuity in uncertain ecosystems, may be slight enough not to cause a potential homeostasis class shift. Potential impact magnitude = (present homeostasis class) x (0.5 x present homeostasis class).

   Rule E. Persistent toxins, like DDT, cause an extreme impact, since their continuing effect on ecosystem characteristics can prohibit natural recovery mechanisms (e.g., by killing reinvading species). Potential impact magnitude = (present homeostasis class) x 5.

Rule F. Certain impacts may have no effect. Potential impact magnitude = 0.

Rule G. Ecosystems presently in class 5 are given a potential impact magnitude = 5 x 5 = 25.

3. The potential impact magnitudes for each impact are summed vertically for each impact category in each ecosystem. These sums are placed in the boxes in the "Impact" rows on the EAW-III. This scheme produces worst-case potential impact magnitudes.

Ranking for alternatives is calculated as follows:

1. One EAW-III is used for each alternative.
2. The staff determines which of all possible impacts are likely to result from each alternative as well as the most likely homeostasis class shifts that will occur. These shifts may be greater or less than the generalized shifts considered for zoning and policy-planning applications.
3. The impact category toxins should be disaggregated as far as possible (e.g., separate columns for heavy metals, types of pesticides, types of air pollutants, and radioactive poisons).
4. The potential impact magnitudes are calculated using the same rules listed for the zoning and policy-planning application.
5. The potential impact magnitudes for each impact are summed vertically for each impact category in each ecosystem. These sums are placed in the boxes in the "Impact" rows on the EAW-III.

6. The "Impact" rows are summed horizontally with the sums placed in the boxes to the right of the impact category--ecosystem matrix. These sums are the potential impact magnitudes of the total ecosystem.
7. The potential impact magnitudes of the total ecosystem are summed vertically with the sum placed in the box, titled "Total Alternative #___ Impact," at the lower right corner of the EAW-III. This sum is the potential total alternative impact magnitude. In the example shown, all possible worst-case impacts from the zoning example are used. These produce the highest potential alternative impact magnitudes that that combination of ecosystems can experience.
8. The staff completes the section indicating the studies needed and time required for the environmental planning of each alternative.

In summary, faced with a decision on policies, zoning plans, or alternative activities, the decision maker should use an ecosystem homeostasis catalog or staff ecologist to complete an EAW-II. He can then compare all listed ecosystems with EAW-I to see the general range of homeostasis in each ecosystem class that may be available to absorb perturbations. A worst-case EAW-III should be completed by the staff so that the decision maker can see in more detail the effects of the impact categories and spot local exceptions to general trends that appear on the EAW-I. The aggregated or disaggregated potential impact magnitudes can be used by decision makers in a variety of ways. The worse-case assumptions can be used in a land-use zoning and policy plans to determine the potential mitigative commitments of each impact X ecosystem. If proposed activities are described by their potential impact categories, they could be placed in the ecosystems with the lowest potential impact magnitude for these impacts. The potential total alternative impact magnitudes and potential total ecosystem impact magnitudes can be used to rank alternatives. They can also guide modifications of plans that could de-emphasize those aspects of the project that cause large impacts.

There are exceptions that undermine any attempt to establish rigid standards or criteria that might dictate a decision. A criterion that prohibits reductions of ecosystem homeostasis would prohibit large-scale agricultural systems that might be needed in the future. A criterion that encourages increases in ecosystem homeostasis would allow conversion of oligotrophic lakes to eutrophic lakes which might be socially unacceptable. The ranking scheme always favors activities in high homeostasis ecosystems over activities in low homeostasis ecosystems, since the probability of degradation is always less. The possibility that a homeostasis class 1 ecosystem can be collapsed by persistent toxins is overshadowed by its relatively low probability of occurrence. It must be emphasized that neither "naturalness" nor "environmental quality" are given any explicit consideration by this ranking scheme or this thesis. The underlying bias is that, in general, some degradation of "pristine" environments that have a "resource value" in their homeostasis is better than total destruction of low homeostasis ecosystems or fruitless attempts to preserve fragile ecosystems at great costs in energy resources. This bias opposes certain social values in certain cases. The author suggests that slight or transient degradations coupled with fewer mitigations may be the wisest method of accomplishing a transition from wasteful affluence or underdevelopment to a state of long-term harmony with recyclible processes in nature.

Environmental-social trade-offs of those policy alternatives are too holistic to be entrusted to a systems analysis that contains the sum of all disaggregation errors and assumptions in both ecologic and social models. These trade-offs should be (and probably are) made at the policy level. By relating ecosystem homeostasis to mitigative commitments, the EAW's give decision makers a tool to use in trade-off bargaining. Instead of passing around projects that require long-term mitigative commitments in highly stressed environments, decision makers can pass around projects and policies that protect the future uses of minimally disturbed ecosystems, they can also boast that their projects conserve energy and resources by achieving goals with fewer unproductive mitigations.

Decision makers must realize that the substantive goals that were never considered explicitly can now be attained and progress toward them assessed. Since the NEPA demands that decisions on policy plans or broad programs should be based on sufficient knowledge to allow prediction of impacts, decision makers must also realize that ecosystems toward the low end of the homeostasis scale require not only more management but also much greater study to develop successful mitigations. Decision makers could choose to sacrifice ecosystems in the possible system failure category without wasted efforts toward fruitless mitigations. However, such a decision should only be possible if the entire program or policy balanced the sacrifice with reduced impacts to other ecosystems. Intensity and scope of studies for the latter approach would still be substantial and the studies have to be done.

The existence of a mandate in NEPA that directs progress toward man's total success has been revealed. If the guidance of the EAW's is followed and environmental studies are complete, man can learn when, where, and how to apply the minimum amount of energy and resources needed to achieve a realistic, persistent fitness curve in the total world ecosystem.

CHAPTER 6

CONCLUSIONS

The EAW's presented in Chapter 5 meet the four objectives stated in Chapter 1. EAW-I educates the decision maker by showing that there are five ecosystem classes, containing nine ecosystem characteristics uniquely related to the ecosystem homeostasis. It also indicates the types of studies required to classify ecosystems in their proper ecosystem and homeostasis classes. EAW-II contains only those ecosystems within the planning area. The decision maker can assess the consequences of general policies and activities by considering the homeostasis of the ecosystems in relation to the range of homeostasis possible in the ecosystem class as shown on EAW-I.

EAW-III uses a simple ranking scheme that can be used for policy planning, land-use zoning, or alternatives comparison. The shifts in ecosystem homeostasis and resulting potential impact magnitudes are clearly stated and can be examined by decision makers, commenting agencies, and interested parties. The decision maker can also consider the investment needed for ecologic studies, if planning is to continue. Use of EAW-II and EAW-III will require interdisciplinary teams of biologists, ecologists, and physical scientists. EAW-III can be used to aid the ranking of alternatives. EAW-II and EAW-III can also help direct commenting and review procedures by indicating the homeostasis of ecosystems and the predicted impacts. The EAW's are compatible with NEPA's procedural methods. The clarity and simplicity of the display of environmental information allows the decision maker to oversee the work of his staff and spot biased parochial conclusions. The value of information relating to the separate impact-ecosystem aspects of a policy or project and the possibility of exceptions to general environmental trends impede decisions based on completely aggregated analyses. The decision maker should require easy access to disaggregate impacts. These are available in the individual impact category X ecosystem characteristic cells, the impact category X ecosystem sums, and the ecosystem impact sums. The total alternative impact sum should only be used after careful study of the disaggregate impacts. The EAW's thus promote efficient organization functions. Objective 1 is satisfied.

Objective 2 requires EAW input relating to NEPA's policies and goal. The concept of ecosystem homeostasis is developed using a long-range, evolutionary time scale to analyze man's uses of energy and resources that can optimize his ability to persist in harmony with nature. The relationship of homeostasis to mitigative commitments provides decision makers with a bargaining tool that can be used in extraorganizational policy processes.

Theoretical and empirical ecology form the foundation for the four major framework divisions that facilitate the relationship of activities to ecosystem homeostasis. Within five ecosystem classes (uncertain, transitional, uniform, constant, and extreme), the nine ecosystem characteristics (species diversity, maturity, productivity, habitat continuity, diversity, periodicity, biogeochemical cycles and size, and indicator species) reveal general trends in ecosystem homeostasis. Four types of studies (climatic and nonclimatic habitat, biota, and productivity) can be used to classify ecosystems in their proper environmental and homeostasis classes. The basic mechanisms that ecosystems use to respond to perturbations are accounted for in combinations of seven ecosystem characteristics (the nine above minus maturity and indicator species) and four impact categories (changes in species composition, energy and habitat, and addition of toxins). The responses within each ecosystem class are generally consistent enough to have predictive value. Objective 3 is satisfied.

The discussion of techniques available for classification studies and impact assessments required by objective 4 reveals that complex ecologic models can produce general results but will not be useful for predicting specific impacts in the near future. Techniques that describe species diversity and productivity are obstructed by poor taxonomies, extensive collection requirements, naturally wide fluctuations of parameters, and operator errors. Simplified techniques, like a sequential comparison index and biomass accumulation ratio, may be useful in limited circumstances. Characterization of habitat is a vast problem. Extensive literature review or new field studies should be the basis for classification and impact assessments.

By satisfying the four objectives, the policies of NEPA are defined and related to the goal through the concepts of ecosystem homeostasis and mitigative commitments. The policies and procedural methods of NEPA are related to the goal of harmony between man and nature through the concepts of homeostasis. The utility of the EAW's as a planning and policy-making guide is strengthened by their foundation in by their foundation in organizational and policy theory and ecology. They are a strong tool useful to approach what this author believes is the mandate of NEPA.

The future application of policies and methods based on NEPA to policy planning, land-use zoning, and program statements represents a significant opportunity to fulfill NEPA's mandate. The budgets that hopefully will be allocated to such planning efforts should allow unparallelled intensity and scope for environmental studies. The conservation of energy and resources and the future alternative uses of ecosystems can be promoted by long-range policies that follow this mandate. Policies that oppose this mandate may allow or encourage long-term environmental changes that threaten man's persistence on earth.

APPENDIX

SECTIONS 101 AND 102 OF THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

SEC. 101. (a) The Congress, recognizing the profound impact of man's activity on the interrelations of all components of the natural environment, particularly the profound influences of population growth, high-density urbanization, industrial expansion, resource exploitation, and new and expanding technological advances and recognizing further the critical importance of restoring and maintaining environmental quality to the overall welfare and development of man, declares that it is the continuing policy of the Federal Government, in cooperation with State and local governments, and other concerned public and private organizations, to use all practicable means and measures, including financial and technical assistance, in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans.

(b) In order to carry out the policy set forth in this Act, it is the continuing responsibility of the Federal Government to use all practicable means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans, functions, programs, and resources to the end that the Nation may—

(1) Fulfill the responsibilities of each generation as trustee of the environment for succeeding generations;

(2) Assure for all Americans safe, healthful, productive, and esthetically and culturally pleasing surroundings;

(3) Attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences;

(4) Preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice;

(5) Achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities; and

(6) Enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

(c) The Congress recognizes that each person should enjoy a healthful environment and that each person has a responsibility to contribute to the preservation and enhancement of the environment.

SEC. 102. The Congress authorizes and directs that, to the fullest extent possible: (1) the policies, regulations, and public laws of the United States shall be interpreted and administered in accordance with the policies set forth in this Act, and (2) all agencies of the Federal Government shall—

(A) Utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decisionmaking which may have an impact on man's environment;

(B) Identify and develop methods and procedures, in consultation with the Council on Environmental Quality established by title II of this Act, which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decisionmaking along with economic and technical considerations;

(C) Include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on—

(i) The environmental impact of the proposed action,

(ii) Any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) Alternatives to the proposed action,

(iv) The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and

(v) Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

Prior to making any detailed statement, the responsible Federal official shall consult with and obtain the comments of any Federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved. Copies of such statement and the comments and views of the appropriate Federal, State, and local agencies, which are authorized to develop and enforce environmental standards, shall be made available to the President, the Council on Environmental Quality and to the public as provided by section 552 of title 5, United States Code, and shall accompany the proposal through the existing agency review processes;

(D) Study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources;

(E) Recognize the worldwide and long-range character of environmental problems and, where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment;

(F) Make available to States, counties, municipalities, institutions, and individuals, advice and information useful in restoring, maintaining, and enhancing the quality of the environment;

(G) Initiate and utilize ecological information in the planning and development of resource-oriented projects; and

(H) Assist the Council on Environmental Quality established by title II of this Act.

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