A GENERAL RESEARCH FRAMEWORK FOR THE STUDY OF RECREATIONAL CARRYING CAPACITY WITH AN APPLICATION TO A HYPOTHETICAL DEER-FOREST-HUNTER SYSTEM

Dissertation for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY
DANIEL JOSEPH STYNES

1976

This is to certify that the

thesis entitled

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FOR THE STUDY OF RECREATIONAL CARRYING CAPACITY
WITH AN APPLICATION TO A HYPOTHETICAL
DEER-FOREST-HUNTER SYSTEM

presented by

Daniel Joseph Stynes

has been accepted towards fulfillment
of the requirements for

Doctor of Philosophy degree in Resource Development

Lewis W. Moncrief
Major professor

Date August 30, 1976

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ABSTRACT

A GENERAL RESEARCH FRAMEWORK FOR THE STUDY OF RECREATIONAL CARRYING CAPACITY WITH AN APPLICATION TO A HYPOTHETICAL DEER-FOREST-HUNTER SYSTEM

By

Daniel Joseph Stynes

Recreational carrying capacity (RCC) is a research area that has been much discussed, but where progress has been less than satisfactory. The concept is characterized by complex and dynamic interactions, interrelated problems and decisions, and multiple, conflicting, ill-defined goals. The concept entails a system of interrelated and inseparable problems and management decisions.

The problem of the complexity and interdisciplinary nature of the RCC concept itself have been exacerbated by the failure to agree on a precise definition of the term, the failure to define management objectives, and discipline specific approaches to the research of RCC. Research efforts to date have included social scientists identifying the social dimension, economists the importance of values, landscape architects the design dimension, and managers the importance of management.

The lack of a general comprehensive framework into which all of these diverse contributions might be fitted has precluded cumulative progress toward an understanding of the concept and resolution of the associated system of problems at recreation sites.

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The presentation of such a general systematic research framework for the study of RCC is the purpose of this thesis. The proposed framework is based on the philosophy, approach, and tools of general systems theory. An "integrative model" for interdisciplinary research is presented, involving the feedback of problems and results between individual disciplines and a common conceptual model of the recreation system.

The conceptual model illustrates how problems and relationships fit together and provides a common communication medium in which disciplines may resolve conflicts and refine research results and problems. Systems tools, including simulation, provide a corresponding set of analytical techniques for combining models from individual disciplinary research efforts.

The suggested conceptual model for the organization of RCC research is a systems model of a general recreation resource management system, consisting of (1) a user subsystem, (2) a resource subsystem, and (3) a management subsystem. The nine possible interactions between these three subsystems provides a scheme for classifying the dimensions of RCC and the corresponding research literature. These include traditional social and environmental dimensions as well as management control of the user and resource subsystems and the corresponding feedback of information to management as additional "dimensions" of RCC.

A corresponding systems definition of RCC is presented, synthesizing the carrying capacity concepts from recreation, wildlife, and regional planning. The recreation system is viewed as a cybernetic one in which management monitors the state of the system and attempts to steer the system to

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The general research framework begins with the identification of the recreation system under study using the general systems model and ninefold classification of interactions as the basic structure. Objectives for the system must be determined and performance measures developed to reflect these objectives. In an analytical treatment one proceeds to model each of the key interactions and to integrate them into a comprehensive model of the recreation system. CC is explored by testing a number of alternative management and use strategies on the model to explore short- and long-term benefits and costs. Performance measures provide the criteria for evaluating alternative designs.

The model does not attempt to generate "optimal" RCC standards, but aims at creating a better understanding of the use decision and its relationship to other management decisions (e.g., scale, design, location) in the context of a dynamic incompletely determined recreation system. In particular it attempts to highlight tradeoffs among different objectives and different user groups that are inherent in distinct use and management decisions.

A hypothetical deer-forest-hunter system is used to demonstrate the operationalization and applicability of the research framework. A combined economic-ecologic model of deer-forest-hunter relationships is developed and the implications of clearcutting, doe harvests, and deer and hunter stockin

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and hunter stocking in generating benefits for hunters are examined. Deer and hunter CCs are discussed in this context, by simulating with different management and use levels.

It is concluded that the RCC concept is basically a suboptimizing one and research directed at comprehensive management of recreation sites might be more fruitfully directed towards the use decision and its role in the broad system of management decisions which collectively contribute to the success in achieving management objectives. The proposed systems model is general enough to incorporate a wide range of management decisions within the management subsystem, thus enabling the analyst to explore the interrelationships among management decisions.

In order to carry out the kind of comprehensive research efforts implied by the systems framework, it is recommended that recreation researchers receive more training in modeling and systems techniques and that a center for recreation research be established to organize, coordinate, and direct long-term cumulative recreation research programs.

"Quick and dirty" systems approaches to recreation management are recommended to organize research and data gathering efforts. Large scale simulation models hold great promise for recreation, but cost benefit studies should be carried out before such efforts are undertaken.

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A DISSERTATION

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Department of Resource Development

1976

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ACKNOWLEDGMENTS

I wish to thank a number of friends and colleagues for their contributions to the completion of this dissertation. Special thanks are due to Lewis W. Moncrief, Chairman of the Dissertation Committee, for his intellectual, moral, and financial support throughout the past three years. I also wish to thank the other members of the committee, Daniel E. Chappelle, Ralph Levine, and Gerald L. Park for reviewing various drafts of the dissertation and their stimulation both inside and outside the classroom.

In addition, I wish to thank Donald Holecek and Daniel Talhelm for reviewing an early draft of the deer hunting model, and Carl Bennett and Ed Langanau of Michigan DNR's Wildlife Division for discussion of deer hunting and management and DNR's deer management research program.

Thanks are also due to other members of the Department of Park and Recreation Resources, including graduate and undergraduate students, staff, and faculty for their contribution to a pleasant and stimulating working environment. Special thanks are extended to Jean Geis for her secretarial assistance and to B. J. White for her help with the figures and typing of early drafts. For the typing of the final thesis, Grace Rutherford is gratefully acknowledged.

The MSU Agricultural Experiment Station is acknowledged for financial assistance during the writing of this dissertation. Finally, I wish to thank P. L. M. Warwick and Clawson and Knetsch for introducing me to the sometimes frustrating, but always exciting field of recreation.

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CHAPTER 1

THE PROBLEM

1.1 Introduction

As the use of outdoor recreation facilities has skyrocketed in the last decade, increased pressures have been exerted on recreational facilities. This has resulted in overcrowding of recreation areas during peak use periods and has contributed to a myriad of problems.

These problems have traditionally been divided into environmental and social. Environmental problems include the impact of users on the environment whereas social problems are usually characterized as "congestion problems." In response to these kinds of problems, the concept of recreational carrying capacity (RCC) has gradually evolved.

Twenty years ago, Dana (1957) recognized the need for recreational land use standards and applied the term "carrying capacity" (CC) to recreation. It was not until use pressures began to build and Wagar (1964) revived the issue that significant attempts were made to understand and deal with the problems of CC as they relate to recreation. In the past decade, an increasing volume of literature has appeared on the subject. Bibliographies by Stankey and Lime (1973) and Butler (1972) list over 200 entries each, and this number has more than doubled in the interim.

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In spite of these research efforts, the concept of RCC is still recognized as one of our most pressing research areas (USDI, BOR, 1974). Thus, it is recognized by researchers themselves that the progress in understanding and resolving the CC issue for recreation has been slow. This is in spite of the fact that conceptual studies of RCC far outnumber the empirical.

This is not to say that progress has not been made. Economists, in particular, have made great strides toward valuing recreation resources and experiences and in modelling tradeoffs that are involved in CC decisions (Fischer and Krutilla, 1972). Social scientists, including sociologists, psychologists, and geographers have contributed to the knowledge of the social component of RCC (Lucas and Stankey, 1973), including the measurement of attitudes, values, and perceptions of different user groups. Ecologists have begun to examine the impacts of human activities on ecological systems, an important component of RCC (Ohmann, 1973).

Thus, a number of disciplines have made contributions to a better understanding of parts of the RCC problem; however, a sound theoretical framework into which all of these diverse contributions can be fitted to clarify the complex CC issue in total is still lacking (Frissell and Stankey, 1972). The basic problem appears to be the interdisciplinary nature of CC problems and the failure to use a holistic approach towards them. Also, the majority of RCC studies have been site, activity or resource specific and not readily generalizable.

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RCC is not a simple problem. It is best seen as a "mess." Ackoff (1971) defines a mess as a system of interrelated and indivisible problems. The RCC mess has traditionally been divided into a social and ecological component. Aside from these two "sub-messes" RCC is also intimately tied up with most other management decisions and problems, including those relating to scale, location, design and intensity. Thus, it is indeed "messier" than most researchers have cared to admit.

1.2 The Research Mess

There are really two messes involved here, and it will be useful to separate them from the outset. First, there is the CC mess itself, consisting of the large set of interdependent problems generally associated with the use of sites either directly or indirectly. The solution of these problems is of interest to managers, users, and planners. While contributing to the resolution of these problems is the ultimate goal of this study, the CC mess itself is of secondary interest here.

This dissertation is primarily aimed at the recreation research community. We are mainly concerned with a mess that has been generated from the CC mess. It consists of the problems in the way that the original CC mess has been treated by recreation researchers.

O'Riordan (1971, p. 1) identifies three characteristics of messes (he terms them "meta-problems"): (1) The difficulty in defining the problem; (2) Incomplete agreement over goals; and (3) The need for an interdisciplinary approach. RCC is readily classified as a mess under these criteria, and the failure to adequately deal with them is largely responsible for the research mess.

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The research mess stems in part from the complexity and interdisciplinary nature of the CC mess itself, but the failure to adequately define the scope of CC problems, the term itself, and the objectives has also contributed to the research mess. The mess is exacerbated by the lack of a suitable general framework or model, reductionist approaches, and the absence of integrative theory.

Researchers are, in effect, faced with a similar kind of overload problem as the recreation site manager. The manager often views his problem as too many visitors; the researcher, too many variables. Both groups have opted for similar solutions to these overload problems. Managers look for simple standards to apply, researchers for simple models. Managers exclude visitors, researchers omit variables. Neither mess is being adequately resolved by these approaches.

Viewing RCC and the research of it as messes forces one to examine a whole host of problems simultaneously. This severely taxes the knowledge, time, and resources of managers and researchers alike. They are both too used to suboptimizing and dealing with problems one at a time. We are only beginning to develop tools and techniques that are applicable to complex systems of problems (Ackoff, 1974).

The purpose of this dissertation is to develop and present a systematic organizational framework for the study of RCC. A framework which is general, comprehensive, and especially suited to treating RCC as a mess is desired, so that the framework might be applied to any kind of RCC problem and might include all dimensions and problems included in, or re

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Before stating the approach and objectives more precisely, it will be instructive to examine the research mess in more detail to give the reader a more precise understanding of the problem under study. There is not sufficient space nor a need to detail all of the problems in RCC research. Many of these are discussed in the literature dealing with recreation research in general (see Brown et al., 1973) and RCC in particular (see Wagar, 1974; Chubb and Ashton, 1969). It will suffice here to limit consideration to the three characteristics of messes identified by O'Riordan, pointing out some of the key problems which have largely gone unnoticed or received scant attention.

1.2.1 Definitional Problems

An important step in any study is the precise definition of terms. Part of the RCC research mess is the absence of a clear and universally accepted definition of the term itself. A study by Chubb and Ashton (1969) on recreation use standards is the only in-depth study of RCC which attempts to formulate precise definitions which are applicable to a wide range of recreation activities and environments. Most other definitions of the term implicitly assume a specific resource type of activity.

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Ackoff (1962) points out that in defining a term, one should examine both its historical evolution as well as the purposes of the inquiry in which it is being used. Part of the reason for the wide variety of interpretations of the term "RCC" is that it has been used to serve a number of distinct purposes. Some have used the term to represent a biological limitation of a site, others physical, and still others social. More recently, a wide range of limiting factors have been implied by the RCC concept.

History of the Term

The RCC concept has essentially been adopted from the wildlife CC concept. The histories of the terms in the recreational and ecological settings are reviewed in Chubb and Ashton (1969) and Edwards and Fowle (1955), respectively. A comparison reveals that recreation researchers are essentially following an identical path 20 years after the wildlife biologists.

Both the recreation and wildlife CC concepts began with rather simple views of CC based on a few physical and biological limiting factors. Wildlife CC began as a limitation imposed on animal populations by the available food supply (Edwards and Fowle, 1955). Soon other factors such as shelter and water were added. Later it was recognized by Calhoun (1949) in his studies of rats that even in animal communities there are social factors which inhibit population growth.

Dasmann (1948) noted that the quality of the animal population is also a factor as a range may support greater numbers of animals at lower quality sta

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Analogues of each of these factors exist for the RCC concept.[1] In fact, some of these factors recognized 20 years ago by wildlife biologists are still not fully recognized in the recreation context. The neglect of dynamics is probably the best example.

Time in general and dynamics more specifically, have received scant attention in the RCC literature. Chubb and Ashton (1969) raise the issue of the temporal dimension, but only treat it in terms of the distribution of use over time. Little consideration is given to the changing environment. Given the dynamic nature of recreational environments, user demands, attitudes and values, management objectives, and each of the other determinants of CC, it is difficult to give credence to static models which arrive at fixed, absolute CCs.

The CC of a site should be an instantaneous measure of the appropriate use level and should constantly adjust to changing conditions on and off the site. Future use should be incorporated in CC decisions by considering expected future demands and conditions when setting present use levels.

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[1]An additional analogue is Frissell and Stankey's (1972) concept of "limits of acceptable change" for RCC which is strikingly parallel to Shelford's Law of Tolerance in Ecology (see Odum, 1971, p. 107).

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The RCC concept, just like the wildlife CC term, has evolved from an initial conception in terms of a fixed limitation in use imposed on man by the environment towards a more dynamic, flexible concept, dependent on values and objectives.

Dasmann (1948) noted that one could support a small high quality wildlife population on the same range as a large low quality herd. Different age structures of wildlife populations can also affect range CC. These questions are in part value judgments as to what the range manager desires. Similar questions are involved in RCC where tradeoffs are involved between quality and quantity of use and between alternative user groups.

Two comments of Edwards and Fowle (1955, p. 589) in regard to the understanding of the wildlife CC concept in 1955, sum up the current state of understanding of RCC.

> It is one of those terms often employed without strict consideration of exact meaning which is used to describe a general conception rather than to express an exact idea. . . . We find that most definitions of carrying capacity are vague and that some are almost meaningless.

The Term Itself

The term CC itself may be more misleading than informative in the recreation context. Wagar (1974, p. 274) criticizes the term for diverting attention away from the ultimate goal of providing benefits and satisfactions for people.

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> Even when qualified as social, the very term "capacity" suggests that reasons for limiting use reside in the character of a specific site, and not in its contribution to human experience. . . . This directs attention . . . away from allocations, tradeoffs, and alternative management practices and explicit analysis of objectives.

Once the problems associated with CC are viewed as a system, treatments of the subject must include many areas not traditionally associated with the term RCC. Thus, once a certain level of understanding of what is involved in RCC is reached, and the associated set of problems is viewed as a mess, it may be advantageous to abandon the term in favor of a broader treatment of comprehensive management of recreation users and resources.

In this thesis, the term RCC will continue to be utilized as a device for getting a handle on the associated mess of problems, but this study will not be constrained by traditional views of what is encompassed by the term and will explore all areas related to the determination of use levels. A formal definition of RCC will be presented in Section 2.1.

1.2.2 Failure to Specify Objectives

White (1966, p. 112) has pointed out the general lack of agreement on goals in resource management.

> There is not a single policy in recent U.S. resource management that displays a unitary unambiguous aim. Several aims are fused, and the most ardent administrators revel in the flexibility afforded by the resulting ambiguity.

Researchers have reveled in this ambiguity as well, being able to select out those parts of the RCC mess they felt comfortable with and to fabricate a set of goals with which they could deal. A case in point is the indirect a

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is the indirect assumption in much recreation research and planning that the maximization of use is the goal of public recreation management. Counting visitors or participants is much easier than attempting to more precisely specify the quality desired and the effectiveness of recreation programs themselves.

In RCC a sustained yield standard has often been used to replace explicit consideration of objectives. Virtually all definitions of RCC are phrased in terms of maintaining a sustained yield of both quantity and quality of recreation experiences. This would seem to imply that current conditions are acceptable, not only now, but for an indefinite time into the future. This avoids considerations of whether current conditions are optimal or whether values and objectives will change over time. It would appear to imply maintaining the existing state of the system without regard to the costs involved in achieving such a goal. A sustained yield standard attempts to impose a fixed norm onto a dynamic system. This is unrealistic.

Wagar (1974, p. 275) has pointed out that "each site has a whole range of potential capacities, each providing different consequences." Someone must specify for whom a site is being managed, whose values count, what quality and character of the environment and experience are desired, and what management and resource constraints are involved. Carrying capacity is meaningless in the absence of a set of values and objectives. Managers and researchers have been reluctant to precisely specify these values and objectives, often pretending RCC is a technical issue, when in reality it is a value choice (Wagar, 1974).

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This study will not attempt to determine objectives for the management of recreation areas, except in the broadest terms. These objectives are highly variable from agency to agency, site to site, and one time to another. The approach taken here is to show how objectives in the management of recreation resources are ultimately related to decisions about appropriate use levels. Thus management objectives will be an intimate part of the definition of RCC developed in Section 2.1.

Putting the determination of objectives aside, the other problem is how to make decisions about RCC in the light of multidimensional objectives. Although tools to deal with "messes of objectives" are still in the developmental stages, a number of options are currently available (see Eilon, 1972 or Freeman, 1970). Linear programming models can be modified to handle multiple objectives by either combining objectives or treating all but one as constraints. Goal programming (Lee, 1972) is a generalization of LP which allows the user to specify priorities for the satisfaction of objectives. By "playing with" either of these programming models by changing objectives, weights, or priorities, the sensitivity of the solutions can be examined.[2] In this way tradeoffs involved in satisfying alternative objectives can be examined. Simulation models are even more flexible in handling multiple conflicting objectives and will be explored in Chapter 3.

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[2]See Rappaport (1967) for a discussion of sensitivity analyses in LP models.

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1.2.3 Interdisciplinary Problems

The interdisciplinary nature of RCC has raised considerable confusion as to how the RCC mess should be approached as well as the more basic question of what the RCC mess is.

Kuhn (1971) distinguishes the interdisciplinary approach from what he terms the unified approach. These two approaches are depicted graphically in Figure 1.1.

> In the interdisciplinary approach a problem is put in the center and all disciplines are brought to bear on it. In the unified approach, an analytical tool is put in the center; one can then branch out from it and apply it to a multiplicity of problems, real and analytical (Kuhn, 1971, p. 137).

The approach of RCC to date has been interdisciplinary. Economists, sociologists, geographers, psychologists, biologists, landscape architects, and others have applied their theories and approaches to RCC problems as they see them. This has resulted in reductionist approaches,[3] as each discipline has selected out those problems and variables of interest to them, generally ignoring a major portion of the RCC mess. Each discipline has defined the problem, the approach, and even the term itself to suit their own purposes.

This has resulted in the neglect of several key factors in RCC. Most resource systems are dynamic, non-linear, stochastic, and contain numerous positive and negative feedback mechanisms and time lags. Strangely enough, it is these characteristics that are most notably

[3]Brown et al. (1973) discusses the reductionist nature of recreation research in general.

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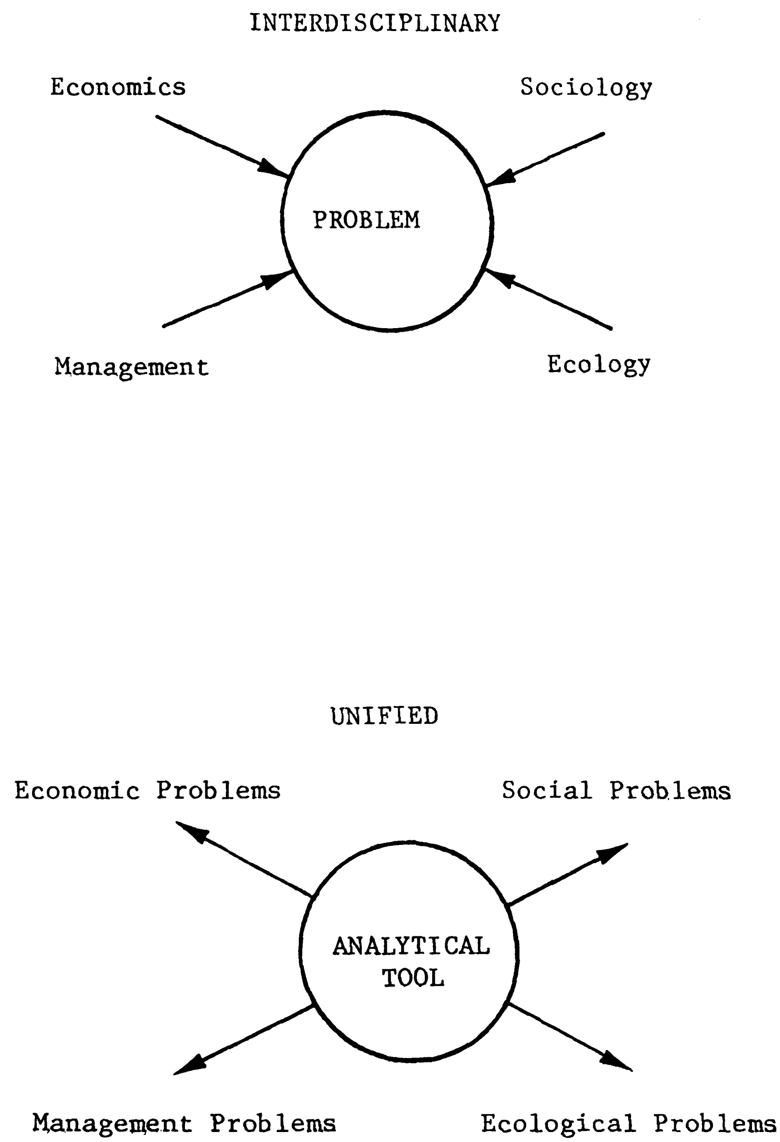

Figure 1.1 --Methods of Social Analysis

(Adapted from Kuhn, 1971, p.137)

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lacking in models of resource systems in general (Jeffers, 1973) and RCC in particular.

A further result of these reductionist approaches has been a tendency to "sub-optimize." Ackoff (1971, p. 238) points out "the optimal solution to a mess is not the sum of the optimal solutions to its component problems treated independently of each other." A prime example of this in recreation is the separation of the CC decision from other decisions relating to scale, design and management. Usually the scale of development and the kind and intensity of management are predetermined and then use levels are set subject to these constraints. This almost inevitably leads to suboptimal allocation of resources as the appropriate use level and management and design strategies are intimately related.

Differences between disciplines have been great enough to hinder the integration of reductionist results into a meaningful comprehensive treatment of RCC. In an attempt to integrate factors identified by more than one discipline, some researchers have attempted to extend the tools and approaches of their own field into other areas, but this usually has resulted in the subjugation of models, methods, and concepts of one discipline to fit those of another (Beddington, 1975).

Fischer and Krutilla's (1972) economic treatment of RCC is a case in point. It is probably the best attempt to date to operationalize the RCC concept by incorporating congestion, environmental deterioration and management all in a single economic model, and yet, the treatment of

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the treatment of the social component would be considered very superficial by sociology standards. The same is true for the management component and the ecological component, all essentially being reduced to single dollar measures of costs and benefits.

The Fischer and Kurtilla approach could be viewed as an example of the unified approach, where the set of analytical tools in question are those of economics. While this has made a substantial contribution, it is still a contribution from a single discipline, presenting their own view of how the RCC mess should be approached. It cannot pretend to be an integration of the disciplines, although it provides a framework to which sociologists and others may add.

Kuhn, of course, has in mind a much broader set of analytical tools than those of economics. (In fact, he advocates those of General Systems Theory.) The unified approach is dependent on the existence of a comprehensive set of analytical tools, equally applicable to all disciplines involved in the mess. Economists and systems scientists have in general made contributions to resolving "messy problems" because their tools have been more widely applicable to complex problems and they have been more prone to meddle in problems of other fields.

There is a trend today toward the unified approach in multi-disciplinary research and planning (Alonso, 1971). This is evidenced by the development of hybrid disciplines like regional science, operations research and systems science. These fields have been based on a set of analytical tools with which to approach a wide range of problems. Th

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of problems. The trend is toward the development of more and more general analytical techniques with wider and wider applicability. This has culminated in the development of General Systems Theory (GST) which claims to be metadisciplinary. The approaches, philosophy and techniques of GST will be discussed in Chapter 3.

This author fully endorses GST, but still has some quarrel with the unified model. It tends to focus too much on the tools rather than the problems themselves and the one-directional arrows indicate no feedback from problem solving to refine the tools or to communicate results between disciplines. The disciplines should not be omitted from multidisciplinary research. They provide the specialization that is needed to get at the details of complex problems. Before specifying the approach recommended here for interdisciplinary research, one additional problem of RCC research will be discussed, as it is a significant aspect of the approach taken here.

1.2.4 Lack of Generality

A key problem with much recreation and RCC research is the lack of generality. The majority of the work that has been done is activity, resource, or even site specific. Smith (1975) calls for more general kinds of studies which he terms "meta-recreation research." "Meta-recreation research constitutes a realm of research in which the primary observations studied by researchers are synthesized or transformed into generalized phenomena."

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RCC studies may be generalized on several levels. The research to date deals with studies of individual sites, resource types (wilderness, lake, forest), activity classes (boating, camping) and a few conceptual studies that treat RCC in a general way within recreation. Almost universally, recreation researchers have felt obliged to stop at the disciplinary boundary, not venturing into wildlife or broader regional and global CC concepts.

The failure to look for common grounds among disciplines dealing with CC has precluded the passing of valuable insights and information between disciplines. The fact that recreation researchers are going through a similar process as wildlife researchers in refining the CC concept has already been noted.

Even within recreation itself there appears to be two distinct groups of CC researchers, one stressing environmental factors, the other social, with little communication between the two. The two largest classes of RCC research, wilderness and boating studies, seldom refer to the work of one another. This is in spite of the fact that they share a common need to predict the distribution of users over their respective resources and determine perceptions of crowding therefrom.

In short, a great deal of insight can be gained by synthesizing past research across inter- and intra-disciplinary boundaries. Such a synthesis of CC concepts will be presented in Chapter 2.

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1.3 The Approach

The primary goal of this study is to present a systematic general framework for organizing the RCC research mess. No attempt will be made to present and compare a number of alternative research frameworks. Instead, a single, general framework will be proposed and its advantages and feasibility for organizing RCC research will be examined by testing its applicability on a specific RCC problem area.

A few biases in the approach are most likely evident from the start and two major ones will be openly stated. First, is the author's "systems orientation." This should be evident from the presentation of the RCC problem as a mess. This initial perspective on RCC problems leads naturally into a systems definition of RCC and a systems model of the RCC mess, which in turn leads to the use of simulation techniques as the analytical tools with which RCC problems are approached. A brief outline of what is meant by the often misunderstood "systems approach" will be given, but no justification of the approach will be made, except as it applies to the RCC problem at hand. The reader may judge for himself whether the systems approach to CC presented in subsequent chapters clears up the RCC mess or helps to organize research efforts.

A second and related bias is reflected in the general "meta-recreation" research approach which is assumed here. Whenever possible, theories, concepts, models and definitions are presented at a more general level than is necessary for the specific discussion. The general meta-concepts are then brought down to the level of specificity appropriate to the context. This makes many of the presentations of much wider appli

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much wider applicability than the RCC context. It is hoped that the reader will benefit from these digressions to the meta-level as much as the author has.

The approach as well as the scope and content of this study can be clarified by examining the key complicating factor in the RCC mess, namely its interdisciplinary nature. Earlier it was pointed out that the interdisciplinary nature of RCC is a primary contributor to the RCC research mess. The unified and interdisciplinary models for research were both found lacking in some respects. Here, the two approaches will be combined, retaining the best features of each. The resulting approach is termed "the integrative approach."

The Integrative Approach

The integrative approach is presented graphically in Figure 1.2. The focus is returned to the mess itself and the integrity and specialization of the individual disciplines are maintained.

The core of the model focuses on the RCC mess. This mess is organized into a system of problems and relationships by means of a conceptual model, explaining how the vast array of problems which make up the mess fit together. A set of meta-tools form the counterpart of the set of analytical tools focused on in the unified model. These tools and techniques are aimed at integrating analytical models of the individual disciplines and enabling the development of more comprehensive hybrid models.

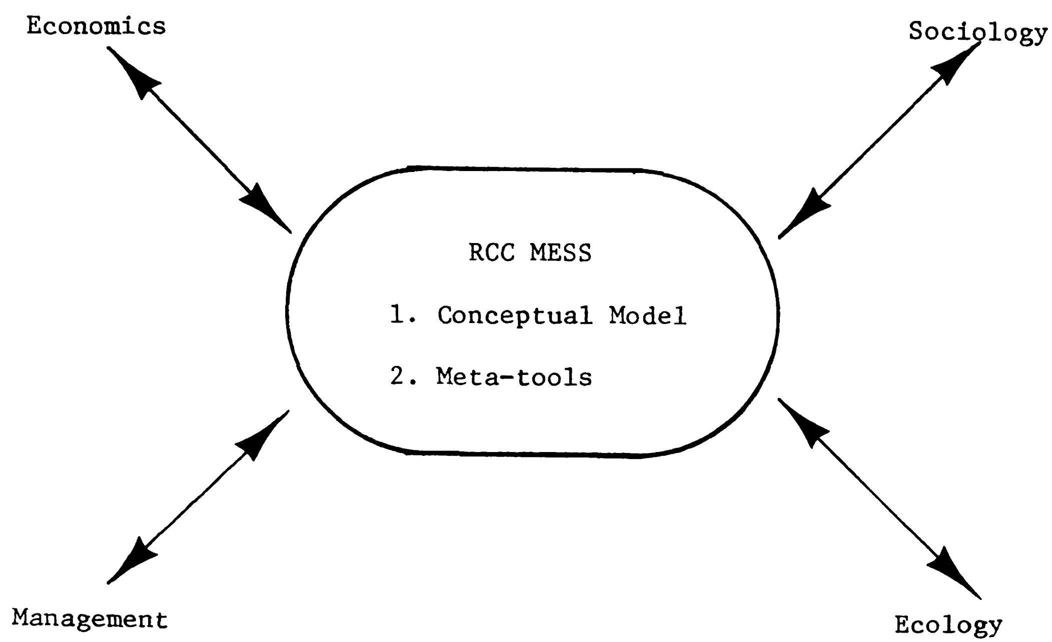

Figure 1.2 -- The Integrative Approach

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The flows between the individual disciplines and the core are two-way flows, facilitating feedback of information between disciplines and the central organizational model. On the one hand, disciplines help to identify the problems which make up the mess. These are fed into the conceptual model which then clarifies how individual problems fit into the overall mess. The conceptual model should not be viewed as a fixed model of the mess, but a learning model which adapts and adjusts to new information or changing conditions.

Individual disciplines still assume the role of identifying component problems, but these problems are refined and clarified by integrating them with problems identified by other disciplines. They are then fed back out as refined research questions. These research problems which flow out to the individual disciplines in turn lead to new flows of information back into the model in the form of answers to research questions or new problems. These feedback flows may lead to refinement of the coneptual model itself as well as generating new questions and problems for other disciplines to tackle or refining old questions and problems.

As specific results within each discipline are translated to fit into the conceptual model, they become comprehensible and relevant to other disciplines. Thus the model serves to fit together research results into a meaningful scheme and communicate these results between disciplines. The basic role of the conceptual model is to organize information and provide a common language to facilitate interdisciplinary communication. This information includes research results, raw data, techni

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raw data, techniques, questions, and problems. As research efforts aim at comprehensiveness in approaching complex problems, a key factor in successful research programs is organization and communication. The integrative framework is designed to meet these needs.

The meta-tools serve a similar purpose as the conceptual model in that they organize and integrate analytical models. Just as each discipline has its own perception of, and approach to, the mess, each discipline has its own set of models and analytical tools. These models differ greatly in character and are not readily combined. Meta-tools which can perform this integrative service will help to organize and refine individual models, techniques and research results.

1.4 Objectives of the Study

The foregoing has attempted to detail some of the problems involved in the RCC research mess. In short, the lack of an appropriate theoretical framework has resulted in what Frissell and Stankey (1972, p. 171) call a "series of individual and non-accumulative efforts" leading to a "single causation explanation of capacity." The problems of definition, approach, communication and generality are symptoms of a missing comprehensive conceptual framework.

The integrative model for interdisciplinary research presented in Figure 1.2 forms the basis for the research framework to be presented here and outlines the program for this study. The integrative model is completely general and might be applied to any mess. The task here is to present the details of the conceptual model and meta-tools for the RCC mess.

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Part I will present a conceptual model and set of meta-tools for the RCC mess. This model will, of course, only be an initial stage of what should be a continuing effort to update the conceptual model and analytical tools based on experience with them in organizing research efforts, solving CC research problems, and communicating results between disciplines.

More precisely, this will include the following objectives:

A. Present an integrative conceptual model of the RCC mess.

   1. Define RCC, synthesizing definitions from specific disciplines and tying the concept to management objectives.

   2. Based on research efforts to date from different disciplines, present a model to organize research results into a meaningful scheme. This model should provide guidance in organizing problems and research questions as well as suggesting gaps in research and directing future research efforts.

B. Present General Systems Theory as a possible set of meta-tools and meta-approaches consistent with the conceptual model and suited to organizing and integrating analytical models from different disciplines.

   1. Examine the "systems approach" as a problem-solving methodology for researching RCC.

   2. Examine the feasibility of simulation to organize and integrate research efforts including problem identification, modeling and data gathering as well as to explore management and policy alternatives relating to CC.

Part II

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Part II will explore the applicability and feasibility of the conceptual model and meta-tools by applying them to a particular RCC problem area.

It should be emphasized that the client for this study is the recreation research community. The principal thrust of this study is the development of a general research framework that might be applied to the study of any kind of CC problem. No attempt will be made to determine the CC of any particular site or indeed, even to make contributions to any particular part of the CC mess. The purpose is to organize the disjointed efforts that have appeared to date and present a framework which reveals how these efforts fit together and gives some direction toward a cumulative research program. The application is included to give the practically oriented reader an indication of how the suggested program might be carried out in a particular instance, and to present some criteria by which the applicability of the general framework might be evaluated.

Criteria to be used to evaluate the framework include:

1. Its contribution to defining RCC.
2. The success in including dynamics, tradeoffs and multiple objectives.
3. Its general applicability to RCC messes.
4. Its capability to organize RCC related research.
5. Its capability to facilitate interdisciplinary communication.
6. The feasibility of organizing and carrying out such a framework.

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7. The applicability of the results (intermediate and end) of the research framework to improving the management of recreation resources.

The evaluation of the proposed framework with respect to these criteria must be largely subjective, as a single, limited application is insufficient to make general conclusions, but can only indicate potential. Evaluations will be based in part on the experience with the application, in part with the ability of the framework to synthesize and integrate research efforts to date, and in part on the internal consistency of the framework itself.

PART I

THE GENERAL RESEARCH FRAMEWORK

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CHAPTER 2

THE CONCEPTUAL MODEL

The conceptual model consists of a general systems[1] model of a recreation resource system and a precise systems definition of the RCC concept. A meta-recreation research approach is taken toward the definition of RCC and the development of a general model. First the definition and model are developed for resource utilization systems in general and then applied to recreation.

2.1 Resource Carrying Capacity: A Synthesis

First, a general resource utilization system is defined. It may be broken down into two basic subsystems: (1) a subsystem of resources, and (2) a subsystem of users of these resources. Here users may include those who merely have an interest in the resources without directly utilizing them. Especially note the use of the term "system" to emphasize the dynamic aspects of both subsystems and the high degree of interaction between them and within each subsystem. Zimmermann's (1964) conception of resources as dynamic and culturally determined is subsumed under this systems conception of resource utilization.

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[1]See Appendix A, Chapter 3, and the systems references cited in the Bibliography for discussions of systems terms and concepts.

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The resource utilization system is best viewed as an open system, subject to influences from its environment in the form of physical, social, political, and economic variables and constraints. Thus the states of both the human and resource subsystems are affected by both endogenous and exogenous forces.

This simple system is represented graphically in Figure 2.1. Numbering of flows are designed to be consistent with subsequent figures. Flows labeled A and B represent exogenous influences on the subsystems. These flows may be considered as two-way flows to include impacts of the system on its environment if desired.

There also exist relationships within and between the two subsystems. Flows 1 and 5 represent interactions which are internal to the user and resource subsystems, respectively. These include relationships between different users, between different resources, and changes in each subsystem which occur over time. Flows between the two subsystems are equally important. Arrow 2 represents the impact of users on the resources. In the process of utilization the resources are generally altered in some way. One often-used dichotomy is the distinction between renewable and non-renewable resources. This is basically a distinction in the way the resources are affected when utilized.

The systems representation of the resource utilization system implies that different resources making up the resource subsystem interact, and utilization of one resource in a certain way may affect other resources as well. Impacts of use on resources may be direct (flow 2)

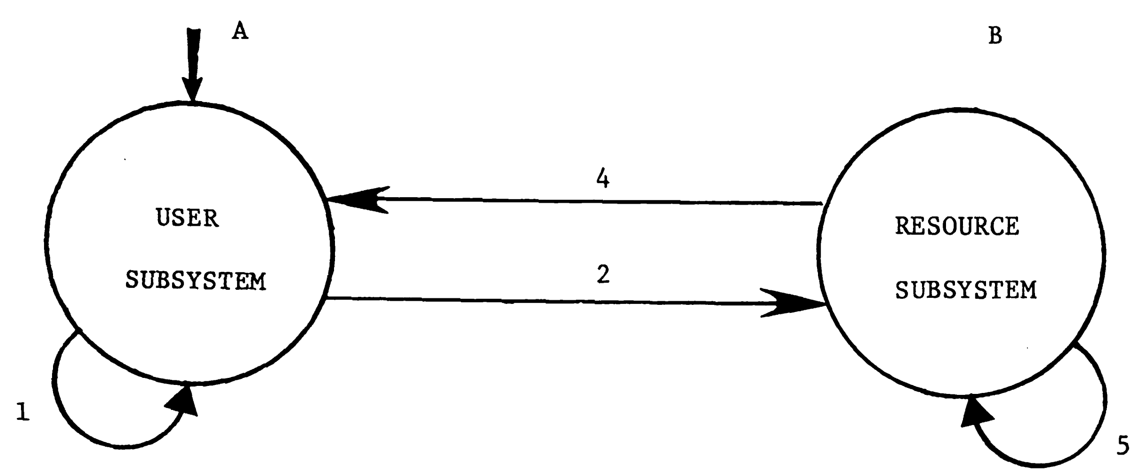

Figure 2.1 -- A Resource Utilization System

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or indirect. Indirect impacts involve combinations of interactions. Thus, for example, utilization of a timber resource by clearcutting may in turn affect a water resource indirectly via sedimentation. This is a two-stage interaction, where first the timber resource is affected (flow 2), and then the water resource is affected by the interaction of weather, soil, vegetative cover, and slope (flow 5).

A fourth flow, labelled 4, represents the effect of resources on users. The users derive certain benefits and incur certain costs in the process of utilization. Also the behavior and attitudes of users are in part determined and in part constrained by the state of the resource subsystem.

2.1.1 Purposive Systems

To define CC, one must associate a purpose or purposes to the overall resource utilization system. Purposes may be divided into two classes: natural and artificial, according to whether or not they are man-imposed objectives.[2] Once human values and objectives are introduced into a system in the form of some sort of management control, one has in part an artificial system. Most systems contain both natural and artificial purposes. An example of a natural purpose is the tendency of objects to move to lower elevations due to the force of gravity in earthly systems.

Generally natural purposes are included within the resource and human subsystems in the form of relationships, feedback mechanisms,

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[2]Simon (1969) discusses the distinction between natural and artificial systems.

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or constraints. Artificial purposes are usually thought of as being imposed from outside the system. For clarity it is useful to include these purposes in a management control system, rather than ascribing them to some vaguely determined environment.

By expanding Figure 2.1 to include a management control subsystem, one obtains the feedback control system of Figure 2.2. This system includes nine classes of interactions among the three subsystems and a third set of exogenous flows to the management subsystem. Flows 7 and 8 represent controls implemented by management which affect the user and resource subsystems, respectively. Flows 3 and 6 are the corresponding feedbacks of information to management, as well as constraints imposed on management by users and resources. These flows will be described in more detail when applied to recreation.

The feedback components of the management control system include both positive and negative feedback. CC studies generally have emphasized negative feedback mechanisms to correct deviations from system goals. Terms like "sustained yield" and "excessive change" imply a self-regulating, deviation controlling system.

Positive feedback mechanisms have been largely ignored in CC studies.[3] Few studies include the natural evolutionary changes in ecosystems or the changes in structure of the user or management subsystems which occur over time. Changes in attitudes of users

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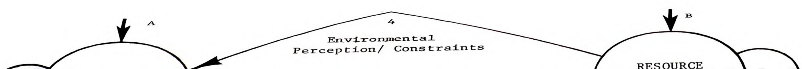
[3]Two exceptions are Langanau (1975) and Hodgson (1976) who both examine adaptation of recreationists to their environment over time. Langanau examines the adaptation in hunter attitudes and behavior to clearcutting. Hodgson speculates that recreationists adapt to crowding by seeking out those areas of tolerable densities.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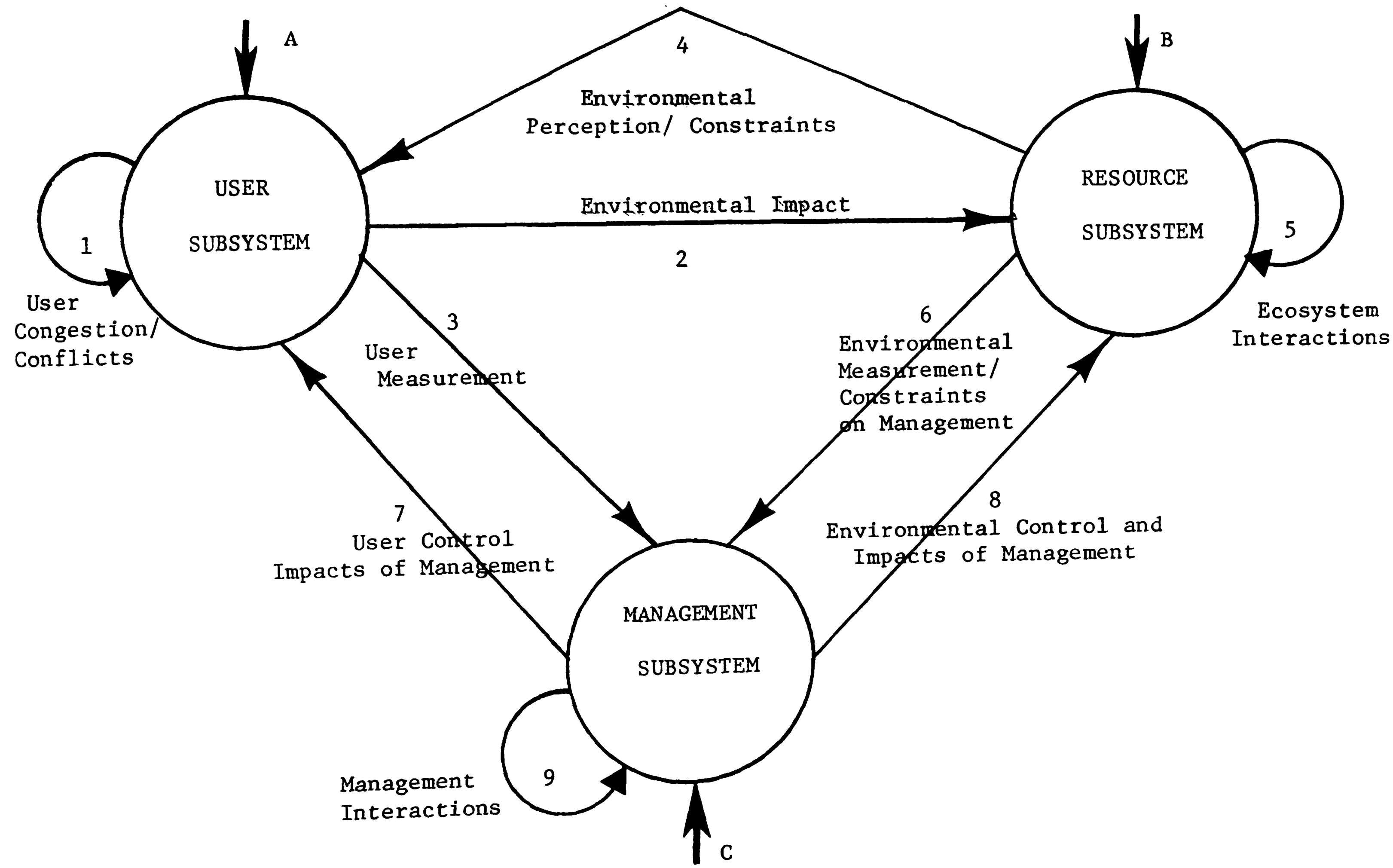

Figure 2.2 -- A Management Control Resource Utilization System

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toward congestion and resource quality, and changing demands for alternative resources are examples of morphogenetic processes in resource systems that affect CCs.

2.1.2 Defining Carrying Capacity

Now that the system and purpose have been discussed, a definition of carrying capacity for a resource utilization system may be given.

> *The carrying capacity of a purposive resource utilization system is the character and level of user activity that best achieves the given purpose or purposes of the system over time.*

There are five key concepts in this definition:

1. A resource utilization system must be given. CC will depend on the scope of the subsystems involved. In particular, what resources, what users, what interactions, and what management schemes are to be included in the system? The failure of many CC studies to identify the system in question is one of the most serious problems of CC studies to date.
2. CC is defined in terms of the "character and level of user activity." Which activities are to be included must be defined in the system identification phase. Simple levels of use are insufficient. Alternative management techniques and system changes to accommodate varying intensities and kinds of use change the character of the resources and the perceptions of them, affecting benefits and costs derived by users.

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3. A purpose or purposes must be ascribed to the given system. In the absence of objectives (purposes) CC is meaningless. Generally systems have a multiplicity of purposes, some natural, some artificial, some vaguely defined, some unknown. A major obstacle in the determination of CCs is the sparcity of well developed techniques for decision-making where multiple conflicting objectives are involved.
4. This raises the question of what is meant by "best." One would like to think in terms of an optimization process, but generally "best" must be thought of in terms of a satisficing criterion (Simon, 1957). This is further complicated by the final factor time.
5. The "over time" raises the issue of changing goals, changing system structure, and their effect on CC. This brings in the dynamic character of CC and intertemporal welfare considerations. When determining CCs, expected future conditions and impacts must be taken into account.

2.1.3 Toward a Concept of Monitoring

The analysis so far makes one point clear. The knowledge of resource systems in terms of interactions, objectives, values, and impacts are all incomplete and uncertain. This high degree of uncertainty in all phases of the research and planning for resource systems makes optimal, absolute, fixed solutions absurd. Efforts to determine "THE CC" of a resource are misguided. The best one can hope for is to locate some ar

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locate some area of tolerance (Frissell and Stankey, 1972) within which the appropriate use level is most likely located at a given point in time. The dynamic nature of resource systems further complicates the matter as we are trying to locate a moving target.

For these reasons, any attempts to determine CCs must be based on a flexible, iterative approach. This means that new information must be constantly fed into the systems to improve models, improve forecasts, and refine system objectives, values, and structure. The inclusion of the two information feedback loops in Figure 2.2 accomplishes this. Control of the system is contingent on the timeliness and accuracy of these flows to steer the system toward the stated objectives, which may also be changing.

It is more meaningful to consider CC as a complex function of the past, present, and future states of the system than some absolute use level that can be calculated in advance. In this way, the management system described above can be viewed as a cybernetic control system which monitors past and present states of the system and constantly adjusts the appropriate use level based on this information and expected future conditions.

2.2 Recreation as a Resource Utilization System

The definition and model of resource carrying capacity is general enough to be applicable to any kind of CC study this author can imagine. At the same time, it pinpoints the five key components of the general CC concept. Its application to recreation resources should be obvious.

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In the interests of "meta-recreation research" the model will be applied to recreation in general to demonstrate the advantages of the systems model for organizing the CC research mess. This should highlight the general dimensions of RCC and demonstrate the advantages of the proposed framework in organizing the multiplicity of interactions that should be considered in determining RCC. It should also lead to further insights into the resource CC model.

Application of the model should begin with the identification of the system in question. At the level of generality used here, this stage will have to be bypassed with only a few general comments.

Identification of the recreation system will often be the most crucial and difficult part of a CC study. The scope, content, and detail of each subsystem will depend on the purposes of the particular study and the knowledge, data, and other resources available. Most studies will require breakdowns of each subsystem into sub-subsystems. Numerous schemes have been suggested for classifying resources (Zimmermann, 1964). Recreationists may be broken down by activity groups or along socioeconomic lines. Management subsystems may be divided along administrative or functional lines. The kinds and accuracy of information required of the model will also dictate the detail and scope of the system.

2.2.1 Dimensions of RCC

Lime and Stankey (1971) identify three dimensions of RCC: (1) visitor attitudes, (2) impact on the physical resources, and

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(3) management objectives. These line up roughly with the user, resource, and management subsystems of the general resource CC model. A problem with this kind of classification is that the key determinants of RCC do not lie within social, environmental, or management sectors, but involve interactions between these dimensions and over time. The determinants of RCC are clarified by examining the nine interactions in the resource CC model depicted in Figure 2.2.

2.2.2 Recreation System Interactions

1. Flows from the user subsystem to itself. This embodies the interpersonal behavioral aspects of the recreation experience, including that part of RCC termed "social CC." It includes conflicts between users involved in the same activity (congestion) as well as those between different user groups, possibly including non-recreational users.

2. Flows from the user subsystem to the resource subsystem. This is the environmental or ecological component of RCC. It includes the impacts of users on water, air, soils, vegetation, wildlife, and physical structures. Studies involving soil compaction, littering, air and water pollution, and general deterioration of sites from use, fall into this category.

3. Flows from users to management. In this group, the feedback of information from users to management is included. Recreation surveys, counting techniques, and other tools to measure user attitudes and behavior all contribute to the flow of information management requires to monitor the state of the system.

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4. Flows from the resource subsystem to users. The topic of environmental perception is included here, as well as more general effects of weather, structures, wildlife, vegetation, and terrain on user attitudes and behavior. The effects of site design on users is also a resource-user flow.

5. Flows within the resource subsystem. This is the general study of ecology, including all of the complex interrelationships between soils, vegetation, air, water, minerals, wildlife, etc. These interactions are characterized by non-linearities, timelags, and feedback effects to a high degree.

6. Flows from the resource subsystem to management. This group might be termed environmental measurement. It is the corresponding flows of information about resources to assist management in monitoring and control of the system.

7. Flows from management to users. This includes any control mechanisms which management might use to control users directly. Education, interpretation, rationing, use restrictions, law enforcement, and permit systems, are typical examples.

8. Flows from management to the resource subsystem. This is the environmental management portion of the control, including construction of facilities and management of the natural environment. Habitat management, cutting and planting of vegetation, watering and fertilizing, and in general any management not aimed directly at people falls in this group.

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9. <u>Flows within the management subsystem</u>. This class of interactions includes the impacts that management decisions have on management itself. The classic case is the example of an irreversible decision such as damming a stream. Decisions made at one time may limit or determine future options. If a complex hierarchical structure is used for the management subsystem, flows within that structure would also be included here.

A glance at the interactions involved in the recreation system shows that the RCC concept has been considerably broadened under this systems model. It now overlaps considerably with the fields of sociology, psychology, ecology, social and environmental measurement, management, economics, education, and design. The model demonstrates the interdisciplinary nature of RCC quite well.

Traditional approaches to RCC have emphasized the first two classes of interactions. The inclusion of the other seven interactions is necessary to close the numerous feedback loops that are involved in resource systems. It is especially important to demonstrate that the impacts of users on the resource eventually feeds back to the user subsystem through the effects of the resulting environment on users. These effects and connections are complicated by the changes which reverberate through the resource system before being detected by users or management. The inclusion of the two information flows to management allows one to include the timelags and inaccuracies associated with management's knowledge of the state of the system in the determination of RCCs. The

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The systems model of Figure 2.2 with its ninefold classification of system interactions provides the primary organizational framework for integrating the many diverse dimensions of RCC. The model succinctly displays the important classes of relationship involved in RCC determinations. In addition, the interactions correspond roughly to disciplinary interests helping to direct and integrate research efforts. Social scientists have concentrated on flows one, three, and four; natural sciences on two, five, and six; and management sciences on seven, eight, and nine.

This completes the discussion of the conceptual model as the emphasis turns to the meta-tools in Chapter 3, where the core of the integrative model is completed.

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CHAPTER 3

META-TOOLS

The systems model of RCC presented in Chapter 2 shows how the dimensions of RCC fit together conceptually. To facilitate cumulative progress toward the resolution of RCC problems and complete the core of the integrative research framework of RCC, a set of meta-tools is required to integrate analytical models and aid in the communication of problems and solutions between disciplines. This requires a common set of techniques and a common language to translate disciplinary jargon into meaningful interdisciplinary communication.

Mathematics is the generally accepted common language of science, but is too broad to give much direction in integrating and unifying models from different fields. In fact, each discipline already has its own set of mathematical models which are particularly suited to the kinds of problems with which it deals. These models differ considerably in character from one field to another and are not easily integrated.

What is required here is a set of meta-tools which apply to the models themselves. Just as the conceptual model of Chapter 2 indicates how the dimensions of RCC fit together, the meta-tools should help to understand how the analytical models fit together.

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These meta-tools should be general, consistent with the conceptual model, and applicable to messes (in particular, able to deal with multiple objectives and dynamic systems). Further, they should be understandable and applicable to all of the recreation-related disciplines involved in RCC research. To serve their role in the integrative research framework, they should be iterative, integrative, problem generating, and theory developing.

No pretense is made about examining all possible sets of meta-tools. Indeed, few such general techniques exist, and a field developed especially to serve the kind of purpose desired here has been evolving over the past 20 years, namely General Systems Theory (GST).

3.1 General Systems Theory

The field of GST began with the founding of the Society for General Systems Research by von Bertalanffy in 1954. Its goals are:

1. To investigate the isomorphy of concepts, laws, and models in various fields and to help useful transfers from one field to another.
2. To encourage the development of adequate theoretical models in fields which lack them.
3. To minimize duplication of efforts in different fields.
4. To promote the unity of science through improving communication among specialists.

These goals are consistent with those of this thesis, which is essentially trying to achieve the same objectives within those fields dealing with RCC or more generally, with recreation. The conceptual model of Chapter 2 is aimed directly at these four goals.

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There is not sufficient space here to detail the broad field of GST. Its scope, history, and content are discussed in von Bertalanffy (1968, 1972), Schoderbek (1975), and Laszlo (1975). Applications to individual disciplines can be seen in volumes of General Systems or collections edited by Buckley (1968) or Schoderbek (1971). For the purposes of this study it will suffice to outline the field and discuss how it meets the needs of the RCC research mess.

First and foremost is its applicability and understandability among recreation-related disciplines. The adoption of systems concepts in recreation will be discussed at the end of this chapter. As for related disciplines, a strong advantage of systems tools is that they have diffused into virtually all of the social, natural, and management sciences. The systems field is truly an interdisciplinary one with names from sociology (Buckley), ecology (Watt, Odum), management (Ackoff, Churchman, Simon), economics (Boulding), psychology (Miller), communication (Meier, Shannon), biology (Weiss), political science (Deutsch), and others. Thus the concepts and techniques of systems theory are known to individuals within each of the relevant disciplines for RCC research. This provides a common language to encourage interdisciplinary communication and promote transfers of ideas and models. The wide application of systems concepts also speaks for their generality and applicability.

For the purposes of this study it is useful to divide GST into three branches: (1) systems philosophy dealing with more abstract, theoretical issues (Laszlo, 1973); (2) systems science built around the "systems a

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the "systems approach," a practical problem-oriented planning/management framework (Churchman, 1968); and (3) systems engineering centered around computers and cybernetics, of which simulation techniques are the principal interest here (McLeod, 1974).

3.1.1 Systems Philosophy

Systems philosophy is the primary theoretical branch of GST, the other two being more practical and problem oriented. Systems philosophy deals with the rationale and scope of the field of GST and in particular with the nature of the holistic view of the world.

Its principal aims are those set forth above for GST and involve the development of what Laszlo (1973) terms second order models, that is, models of models. Much of the work in systems philosophy has been the development of general concepts which are universally applicable to all systems in hopes of developing an integrated theory of complex organization. The advances in systems philosophy are particularly appropriate to the study of messes.

The basic common core of terms which have evolved from 20 years of GST development are reviewed in Appendix A. More thorough treatments are available in Laszlo (1972) and the other systems references cited in this chapter. It is hoped that the flavor of systems philosophy can be gathered from the approach to CC in Chapter 2.

3.1.2 The Systems Approach

It is difficult to identify "the systems approach." Indeed, a number of distinct planning and problem-solving methodologies fall within the sc

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within the scope of the term. These range from straightforward applications of operations research techniques, to computer simulation, to more general management and planning approaches. Here the concentration is on the broader planning/problem-solving approach, leaning somewhat toward the eventual construction of a simulation model.[1]

Most of the variations in the understanding of the systems approach share the following common stages:

1. A system identification phase usually begins the approach. Here the system, its subsystems, components, and interactions are defined. This usually includes the separation of the system from its environment and begins the process of selecting out the crucial variables and relationships from the real world system. Note that the identification of the recreation system is a key component of the definition of RCC in Chapter 2. The systems model of resource CC in Figure 2.2 provides a systematic framework for identifying the recreation system by outlining the three basic subsystems and the kinds of interactions included in each of the nine classes of interactions.

2. Subsequent to, or concurrently with, the system identification phase is a stage in which the objectives or goals of the system are defined. The systems approach allows for the inclusion of multiple and even conflicting objectives. Just as systems techniques are designed to deal with messes of problems, they must also be capable of handling "messes of objectives." This phase attempts

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[1]See Manetsch and Park (1973) for a more complete discussion of the systems approach in this context.

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3. With the system and objectives defined, the next step involves the construction of one or more performance measures by identifying corresponding performance variables. The performance variables measure the effectiveness of the system in meeting the stated goals. Here the question of what is meant by "best" must be confronted. This is a critical stage as it is here that weights and values must be assigned to objectives and measures developed to indicate how well the system meets these objectives.

4. When being applied to a management, design, or planning problem, a stage in which alternative solutions or system designs are generated follows the development of performance measures. This may involve a brainstorming session to generate alternative plans, management strategies, or system controls.

5. The brainstorming phase is followed by an evaluation phase in which the feasibility and effectiveness of each alternative is examined. First, alternatives are weeded out according to general infeasibility due to political, social, economic, physical, or legal constraints. Then remaining alternatives are tested for their effectiveness in meeting the objectives defined in step 2. Here the performance measures are used as the criteria for judging effectiveness of alternatives. In CC studies, this phase may involve the testing of various management strategies and use intensities to examine the benefits generated and costs incurred under each alternative,

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including both short- and long-term effects. The evaluation phase generally works from some kind of model of the real world system developed in conjunction with the identification of the system. Often this takes the form of a computer simulation model, although this need not be the case.

6. Finally, one or more of the alternatives are selected and implemented.

The most important aspect of the systems approach is its iterative nature. One cannot really define separate stages that are carried out in sequential order. One generally makes a little progress on each stage and then returns to earlier stages to refine what has been done there. The system itself, together with the objectives, performance measures, and alternatives are all refined together with progress in one phase usually leading to further revision and refinement in other parts.

In short, the systems approach is a holistic version of the scientific method in that results are never final. Work done in earlier stages is always subject to revision. Thus the systems approach is completely consistent with the integrative framework for interdisciplinary research. Further, it satisfies a number of the other needs set out at the beginning of this chapter for the set of meta-tools.

Most important is the flexible iterative nature of the approach. This is what makes it theory developing and problem generating. The constant feedback of information to earlier stages ensures a learning model and if

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model and if continued through the evaluation and implementation phases results in a monitoring system as described in Chapter 2. The learning nature of the approach is consistent with the goal of this dissertation to create an understanding of the RCC mess rather than to generate "optimal solutions."

3.1.3 Simulation

The systems model and definition of CC together with the systems approach to the study of RCC leads naturally into the use of simulation techniques as meta-tools for the anlytical study of RCC. McLeod (1974, p. 59) defines simulation as "the use of a model to carry out experiments designed to reveal certain characteristics of the model, and, by implication of the idea, system, or situation being modeled." Although simulation experiments may be carried out on practically any model, in discussing their applicability to messes like RCC we are primarily concerned with large-scale computer simulation models.

Aside from arising rather naturally from the approach taken so far, such simulation models have a number of advantages over other classes of models in dealing with messes.

Advantages of Simulation Models

First of all, simulation models are extremely flexible, having the ability to integrate analytical models of vastly different character. Thus, for example, one can combine an ecological model in the form of a set of differential equations with a rather simple model of social attitudes or perceptions maybe in the form of simple indices or scales constructed f

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constructed from selected environmental variables. As Hamilton (1969, p. 94) noted in his simulation of river basin activities,

> of the quantitative methods available in general, the simulation approach places the least restrictions on problem representation. Practically the only requirement is that variables be quantifiable and relationships between variables be defined.

In addition to the advantage of flexibility for integrating different component submodels, simulation also permits the examination and testing of a number of distinct alternatives on the same basic model structure. By replacing, adding, or deleting different component parts of the model, quite distinct system designs and management strategies may be tested.

Second, simulation models are especially suited to the analysis of messes as they are capable of treating the temporal dimension in a meaningful way and can also handle multiple objectives. The inclusion of the dynamic aspects of recreation systems in the determination of use levels is a key consideration of this study and simulation models are an excellent vehicle to illustrate dynamics of systems.

The other key element is the presence of multiple conflicting objectives. Simulation models are well equipped to handle such situations as there is no requirement that a single objective function be specified or that objectives even be measurable in commensurable units. Numerous distinct performance measures, values, and weighting systems may be examined simultaneously on the same system and subjective decisions made based on a number of distinct measures of system performance. This will be illustrated for CC in the application.

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> The [simulation] model is not a device for producing optimal or single valued projections. Instead, it can be a means of facilitating understanding of complicated systems of relationships relevant to policymaking (Hamilton, 1969, p. 55).

This is the essence of the objective of this study and the approach taken toward simulation modeling in the application.

The fact that simulation models meet certain structural requirements for studying CC is not the principal reason for their use here. It must be remembered that the purpose of this study is the organization and direction of research efforts, not the determination of CCs. While simulation models have the potential for ultimately contributing to policy analysis, one component of which involves the determination of use levels, this is not the primary role advocated here.

The existing state of knowledge of recreation systems may not yet permit the construction of comprehensive simulation models which can essentially make decisions for managers. Large scale, long term research efforts will be required to develop such models and the benefits derived may not justify the costs. Cost benefit studies of such projects is one of the research areas which needs to be pursued before such projects are undertaken.

The role advocated here for simulation is in its contribution to theory development, the advancement of knowledge of the system under study, and the organization of research and data gathering efforts. Raser, Campbell, and Chadwick (1970) cite five ways the construction of simulation models spurs theory development.

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1. Confrontation--modelers must confront what they know and don't know.

2. Explication--simulation modeling forces explication, precise specification of relationships and assumptions.

3. Expansion--it forces a broadening, a more comprehensive view.

4. Involvement--it stimulates the researcher to fill in the gaps.

5. Serendipity--simulations are serendipity prone, revealing new problems, new solutions, new approaches, and new hypotheses.

Thus, the construction of simulation models can make significant contributions to the organization and direction of research efforts even if never completed. The model building process reveals gaps and indicates directions for research. The process of attempting to define, measure, model, and integrate the wide variety of variables and relationships encountered in RCC studies should lead to more precision in the definition of RCC and the surrounding body of theory in regard to its determinants.

It should reveal gaps in definitions, in measurement, in specification of objectives, in understandings of relationships, and in decision-making tools. These gaps provide the incentive and direction for research. In this way, modeling in general, and simulation modeling in particular, are important links in the research process and integrative interdisciplinary framework.

Disadvantages of Simulation Models

While simulation models have been presented as the ideal tools for this study, there are a number of drawbacks of simulation modeling. Schultz and Sullivan (1972) point out three.

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1. It provides specific case results, requiring replications to produce more general results.

2. It usually requires more effort in constructing the model.

3. It can lead to more apparent realism and consequent danger of forgetting the limitations of the model.

In this case, the fact that a single optimal solution is not generated is viewed as an advantage. This study is looking for understandings of CC problems rather than "solutions."

The greater effort required in construction can mostly be attributed to the natural tendency to develop more comprehensive flexible models than would be attempted using other techniques such as programming models. The tendency toward involvement and expansion noted by Raser generally leads to greater comprehensiveness and complexity than originally intended. The major problem is often deciding where to stop in simulation model development. There can be significant scale economies in developing models to deal with large classes of problems (i.e., messes).

Two major constraints in the development of simulation models for recreation are the lack of appropriate data and the lack of trained personnel with the necessary modeling skills and awareness of recreation systems. Existing data systems generally do not meet the needs of simulation models and simulation models have an unquenchable thirst for data. Data limitations are particularly apparent in trying to model dynamic systems. Comparable time series data for recreation systems is almost non-existent.

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Recreation researchers trained in modeling and simulation are equally in short supply. There are no canned computer packages for simulation modeling. Each simulation must be developed from scratch and considerable expertise in modeling and computer programming is desirable.

The final problem of too much realism in simulation models may be the most serious. It can be minimized by clearly stating all assumptions. The failure to do so is a common one in the use of models in the social sciences (Jeffers, 1973).

3.2 Simulation and Systems Approaches in Recreation

Systems concepts and techniques have diffused into most fields of study in the past decade and recreation is no exception as terms like "recreation delivery system" have crept into the literature. However, adoption of systems techniques in recreation has been limited to a great extent to the broad popular conception of systems in terms of a general holistic approach to planning and management.

The most popular branch of systems for recreation has been operations research. Much of the recreation research literature that claims to take a systems approach falls into this category. These include numerous trip distribution models (Chubb and Ellis, 1968; Cesario, 1969, 1975; Ellis and van Doren, 1967) and several recent applications of linear, quadratic, and goal programming to CC determination (Menchik, 1973; Penz, 1975; Schuler and Meadows, 1975).

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Attempts to develop comprehensive, dynamic models which integrate social, ecological, and management components in a meaningful way are still lacking. The contributions cited above are primarily discipline specific approaches with trip distribution models being the approach of geographers and programming models those of operations researchers/management scientists. To these we might add the contributions of economics (Fischer and Krutilla, 1972; Anderson and Bonsor, 1974). Thus, almost without exception quantitative and systems approaches to RCC have come from outside the recreation field per se. This is further evidence of the lack of modeling skills within recreation.

This is not to say that only "recreation people" can do recreation research. The above are all substantial contributions. The point is that it is only with great effort that geographers, economists, etc. can achieve truly comprehensive interdisciplinary approaches to RCC. This is where the integrative framework must play a major role in putting together studies like the above.

Two programs of research deserve special mention as examples of the beginnings of comprehensive systematic approaches to RCC problems. Coincidentally both involve a simulation model. Most extensive is the research program of the U.S. Forest Service on wilderness management. Their long term research program includes a wide variety of studies which begin to pinpoint directions for possible resolution of CC problems in wilderness forest environments. The works of Lucas, Stankey, Hendee, Lime, Frissell and others cover

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the entire range of social, ecological, and management dimensions of RCC, and are the best example of a cumulative research program within recreation.

One important output of their research program has been the development of a wilderness trip simulator (see Smith and Krutilla, 1976, for a description of the model). A research program directed at the development of a similar simulation model for water-based recreation was carried out at North Carolina State University for the Water Resources Research Institute of the University of North Carolina (Hammon et al., 1974). Both models are primarily trip distribution models in which an attempt is made to simulate travel patterns of users over the respective resources and determine perceptions of crowding therefrom. The key difference in the two situations is that the wilderness model uses a linear trail network, while the boating model must deal with a two-dimensional spatial system. This made modeling of the waterbased system much more difficult.

Both models focus on the social CC concept and neither includes an ecological component. An advantage of the simulation approach is that ecological components could be added to the models that were developed.

It is a little premature to judge the success of these two applications of simulation to CC problems. The North Carolina State study has not been widely publicized and results of experience with the wilderness trip simulator are just beginning to appear (Smith and Krutilla, 1974, 1975, 1976).

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A comparison of the two studies does permit a few observations on applying simulation techniques in recreation. In terms of a final product, the wilderness simulator has been far more successful than the North Carolina State study as no operational model appears to have been produced in the latter case. The wilderness trip simulator has been applied to a real world system, the Spanish Peaks Primitive Area in Montana, and with suitable data may be applied to virtually any simple trail system.

The wilderness simulator was preceded by considerable research to identify the relevant variables and relationships whereas the boating study had considerably less background research. The wilderness simulation study had considerably larger funding and extensive assistance from IBM and RFF (Resources for the Future) in model development. The problems involved in modeling the wilderness trail system were considerably more clearcut than in the boating case due to the linear trail network, more uniform travel speeds and directions, and limitation to basically two user groups, hikers and horsemen. A simple performance measure of trail encounters proved easier to work with than North Carolina State's attempt to develop sophisticated models of perceptions of crowding based on a complicated mix of variables.

The complexity of the original boating model required extensive data gathering and created a number of measurement problems which may have proved insurmountable. The model reported in Hammon et al. (1974, Part II) relies heavily on multiple linear regression models and attempts to include a wide range of activities including boating, water skiing

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water skiing, sailing, and canoeing. The North Carolina State experience may indicate that a detailed, empirical approach to the initial simulation of recreation systems may not be the best, as it raises considerable measurement and calibration problems. The wilderness trip simulator used a more deductive approach relying on more heuristic validation techniques.

3.3 Summary of the Research Framework

The basic framework for organizing RCC research is now laid out. The integrative model for interdisciplinary research (Figure 1.2) with the RCC mess at the core provides the overall communicative structure of the framework. The systems model of a recreation resource utilization system (Figure 2.2) and the definition of CC provide the initial stage and basis for the conceptual model of the RCC mess. The systems approach and simulation techniques provide the operational and analytical components of the research framework. All of these components are consistent and complementary.

In attacking a specific RCC problem area, one begins with the identification of the system and CC mess in question. The systems model and ninefold classification of interactions provide the basis for the identification of significant relationships. The three major subsystems must be defined and significant representatives of each of the nine classes of interactions selected for modeling. These relationships must be modeled and then fitted together into a comprehensive simulation model.

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Objectives for the system must be determined and performance measures developed to measure the effectiveness of the system in meeting each of the objectives. Once the model, objectives, and performance measures are developed, alternative management strategies and system designs may be examined. In setting CCs, alternative use levels and management strategies could be tested on the simulation model to examine long- and short-term impacts of use and management, and to evaluate the alternatives using performance measures as indicators of how well each alternative meets the objectives set down for the system. The outcome would involve the selection of both a use level and a set of management strategies designed to complement each other in meeting system goals. The use levels and management approach might both change with time and will require continual reevaluation based on changing conditions within the real world system.

Such final "optimal" use and management decisions will not be clearcut and need not even be made. The process of carrying out the study of RCC in a systematic way should lead to a better understanding of the RCC mess and the corresponding impacts of alternative use levels and management strategies. This improved understanding should help the researcher and manager make better subjective decisions related to RCC based on the experience with the simulation model.

PART II

AN APPLICATION OF THE FRAMEWORK

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CHAPTER 4

INTRODUCTION TO THE DEER-FOREST-HUNTER (DFH) SYSTEM

This dissertation does not conclude with the completion of the suggested theoretical framework for organizing RCC research. Only through many applications of this general framework to specific CC messes can its suitability and applicability be tested. The application and implementation of the framework is also an integral part of the integrative model as applications will help to refine the conceptual model and the meta-tools and generally contribute to better understandings of RCC. The application here will start this refining process and will also serve to illustrate a number of points made earlier in regard to dynamics, objectives, tradeoffs, management, and other dimensions of RCC.

Before proceeding into the application, a few points should be noted. First and foremost, the object of the application is not to determine the CC of a particular site, but to clarify the research framework, the RCC mess, and the organization of research efforts. Given the current state of understanding of most recreation systems and their goals, it is doubtful if attempts to determine "THE CC" of such systems are meaningful. The best that may be expected of research is to provide a better understanding of the problems that are involved including t

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including their interrelationships and the tradeoffs that are implicit in alternative management and use decisions.

As the application is for demonstration purposes, only selected components and relationships will be treated in detail. An attempt will be made to select those components which are most readily generalizable to other kinds of RCC messes and which can best contribute to an understanding of the research framework proposed in Part I. The comprehensive and multidisciplinary nature of the proposed framework precludes full treatment of the subject in a one-man dissertation. In particular, demonstrating the ability of the framework to direct and stimulate research efforts in many disciplines can only be indicated. The author's limitations in expertise in ecological and behavioral areas will be apparent.

Modeling will be kept simple and sophisticated discussions of calibration techniques will be avoided. A hypothetical site will be used to avoid data gathering problems, but general data needs of the model will be discussed. Being a demonstration on a hypothetical site, the actual numbers generated are of little significance; however, in all cases reasonable models have been selected and calibration has been aimed at achieving "reasonable system behavior" based on the author's knowledge of deer-forest ecosystems in Michigan. The emphasis is on a deductive rather than an empirical approach to the modeling of the system. In many ways, the author's limited knowledge of deer hunting has been an asset as being unaware of the complexities of the system, it was easy to focus in on the most obvious relationships. Undue complexity

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complexity in the early stages of modeling can make the task impossible to complete. Parameters are inserted freely so that the model might be calibrated for a wide range of sites.

4.1 Selection of the Demonstration Problem

The selection of a sample RCC mess was based on a number of factors including interest of the author, availability of information, and most importantly, its suitability for demonstrating general kinds of RCC research problems.

A hypothetical deer-forest-hunter system (DFH) was selected. This has enabled the author to draw upon preliminary studies of Michigan's Department of Natural Resources on deer and hunter management.[1] Also, the choice of a system involving forest, wildlife, and recreationists will facilitate comparisons of the ecological, social, and wildlife CC concepts, demonstrating the interrelationships between the three stocking decisions: (1) the timber stocking decision, (2) the deer stocking decision, and (3) the deer hunter stocking decision. Other recreational and non-recreational uses of the forest may be examined also.

The DFH CC problems point up a typical problem of one-discipline approaches to multidisciplinary problems. Research on deer CC is extremely unbalanced with considerable detail on the behavior of the ecosystem and virtually none on the principal harvester,

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[1]See Bennett (1974) for a brief overview of the research program.

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the deer hunter. The more comprehensive framework for CC research presented here can reveal these gaps and suggest programs of research to fill them.

Unlike the DFH system, many RCC messes are plagued by incomplete knowledge of the user-environment interactions, and in particular, the recovery of ecosystems from excessive use. For the purpose of this study, recovery of the system involves a forest growth and deer population model, both of which have been modeled quite extensively. The impact of hunters on the system may be limited to the depletion of the deer herd, also simplifying modeling. The examination of the impact of use and recovery of the forest ecosystem should yield insights into systems where user-environment interactions are less well understood.

At the same time, the DFH system presents an opportunity to examine the potential of the research framework in developing combined economic-ecologic-social models by adding the behavior and valuation of hunters to the standard ecosystem approaches to wildlife CC. If one of the objectives of wildlife management is the generation of benefits for hunters, the hunter subsystem must be much better understood to determine appropriate forest, deer, and hunter stocking levels.

The Demonstration

The research framework summarized at the end of Chapter 3 will be followed in developing a model for the DFH system. The systems approach, in conjunction with the general RCC conceptual model, will be used to identify the system. This chapter will begin the identification process by l

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process by laying out the scope of the subsystems and the interactions to be considered. Chapter 5 will proceed with the modeling of the system, precisely defining the variables and relationships. An attempt is made to present the flavor of the integrative framework in the development of a model of the hunter subsystem.

Chapter 6 examines the contribution of the meta-tools in integrating economic and ecologic models and examines the potential contribution of simulation in stimulating and directing RCC research efforts using the DFH model as an example.

The subsystems and relationships included in the model are purposely limited in this demonstration. The user subsystem is limited to hunters and the resource subsystem is limited to a single uniform site (essentially a point). Such a system is sufficient to illustrate the proposed research framework and the ability of the framework to develop more comprehensive treatments can be indicated at the same time without getting bogged down in the details of an extremely complex model.

4.2 System Identification

The identification of the deer-forest-hunter system does not begin with an exhaustive and complete identification. This is neither possible nor necessary. The scope and content of the system, like all other parts of this study, will be refined and clarified as later stages in the systems approach are tackled.

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To begin the process it will suffice to present a general definition of the scope of the system in question. The basic problem is the determination of appropriate stocking levels for deer and deer hunters along with appropriate deer and hunter management strategies. It is immediately apparent that the deer and hunter stocking problems cannot be treated in isolation.

The larger problem under consideration is the management of public forested lands. The guidelines for the management of such lands are represented in the management of federal lands under multiple use sustained yield criteria. Seven major uses of public forested lands are generally identified: timber, recreation, wildlife, watershed, grazing, minerals, and wilderness. For the purposes of this study only the first three will be considered with the timber resource treated primarily in relation to its use for recreation and wildlife. The omissions are in part to keep the study manageable, and in part a result of little conflict within Michigan on public forested lands between the omitted uses and deer management.

Timber will be treated in terms of its visual impact on hunters and as a determinant of deer food supplies. Deer will be the only wildlife representative and recreationists will be predominantly represented by firearm deer hunters, although non-consumptive users of deer will be mentioned. As a first step in the identification process, the three subsystems and nine classes of interactions may be broadly defined.

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Subsystems

User Subsystem:	Deer hunters
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Management Subsystem:	Treated exogenously as a single autonomous agency.

The hypothetical area may be assumed to be in Michigan and to be approximately 10 square miles in area. There is assumed to be no migration of deer into or out of the study area. It is also assumed that all hunters come from a common origin and do all of their hunting on the given area.

Interactions

User-user:	Congestion of hunters as it affects satisfactions
User-resource:	Harvesting of deer by hunters
Resource-resource:	Deer feeding, plant growth, food production, deer population model
Resource-user:	Hunter perception, satisfaction, and valuation of hunting experiences.

The management subsystem is treated exogenously so that flows to management will be treated as outputs and flows from management as inputs to the system in the form of management controls or system design changes.

User-management:	Measurement of aggregate satisfactions and benefits
Resource-management:	Measurement of the state of deer and forest populations

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Management-user:	Hunting controls to include control of the numbers and kinds of hunters and which age/sex classes of deer may be legally hunted.
Management-resource:	Habitat management (clearcutting), and deer stocking
Management-management:	These relationships will not be modeled, but may be examined indirectly in simulation experiments.

4.3 Some Omitted Variables and Relationships

Being a demonstration, a number of variables and relationships have been omitted from direct consideration. In particular, non-hunting uses and non-deer related aspects of the DFH system will not be treated directly in this study. A number of externalities associated with deer management such as agricultural crop damage, highway accidents involving deer, and impacts on vegetation and other wildlife will be left for the reader to see how they might be incorporated.

Conflicts between hunters and other users will not be treated, but use conflicts will be illustrated using two distinct groups of hunters. Other user groups could be added by linking them to the rest of the system by means of another set of interactions.

The most critical and complicating dimension being omitted in this application is the spatial dimension. The simulation model to be developed here will deal with a single site and will treat hunting pressure as an exogenous input. It is assumed that all hunters come from a common origin, incur the same transportation costs, and do all of their hunting at the given site. These assumptions are of course unrealistic

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unrealistic, but are both justifiable and necessary in developing the initial formulation of the simulation model.

The model to be developed will include a number of parameters so that it might be used to represent a number of distinct forest areas. Thus the model aims at ultimately being able to deal with a system of hunting areas, each with different parameters as to the stage and character of forest growth, deer food supplies, and deer populations.

With a system of spatially distributed hunting areas, use may also be simulated using an allocation model. Gravity and simulation models have been used quite extensively to allocate recreational use among a spatial network of sites (Chubb and Ellis, 1968; Talhelm, 1974; Cesario, 1973, 1975).

Such models generally include a set of origin nodes (from which hunters emanate) and a set of destination nodes (the hunting areas). Hunters select sites based on distance, quality (deer densities and other site factors), information, and economic and time constraints. By linking such an allocation model with a system of hunting areas, one could first simulate the distribution of hunters to hunting areas and then use the on-site hunting and ecosystem models to predict the number of kills and the hunting benefits generated. The ecosystem model could then simulate the recovery of the deer population at each site for the following hunting season.

Such a more-comprehensive model would allow consideration of a wider variety of management controls including strategies to control the distribution of hunting effort and to direct different kinds of hunters to

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hunters to those areas where they would receive the greatest benefit. Any such attempt raises a number of research questions as to how hunters select sites. In particular, the relative influence of distance, site quality, congestion, and hunter knowledge must be known. This more comprehensive model illustrates that CCs cannot be determined for a single site. Hunters who are excluded from one site will most likely go to an alternative site. This may impose congestion or deer herd depletion costs on the substitute site. Ideally, the use levels for all sites should be set in a single simultaneous analysis.

By treating hunting pressure as an exogenous variable in the model to be developed here, another dimension of RCC is being ignored. This might be termed the demand factor. If use pressure for a given site exceeds the established CC, then the CC should adjust to the amount of excess use pressure. This is due to the fact that costs are involved in excluding users. This includes both the management costs of implementing a use limitation control as well as the costs incurred by potential users who are excluded (for example, the extra costs incurred to travel to a more distant site). Both of these costs may be assumed to be directly related to the amount of excess use pressure. If these "exclusion costs" exceed the costs imposed on the environment and other users by admitting more users, then "best" use levels must increase with increasing use pressure.[2]

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[2]The demand factor explains why use standards for recreation allow greater use in urban areas than at similar sites in rural areas. There is greater use pressure in urban areas and CCs must adjust accordingly.

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Undoubtedly there are numerous other variables and relationships which have been omitted and may be considered important by researchers from various disciplines. The selections made in this application are based solely on the author's perception of the system. Ideally an interdisciplinary team should be involved in system identification. This is where the different disciplines fit into the integrative framework to identify the problems and the system itself.

4.4 System Objectives

As noted earlier, most recreation systems and treatments of RCC have been characterized by a failure to precisely specify management objectives. In most cases, deer-forest-hunter systems are no exception. Hendee (1969) has noted the lack of clear policy objectives for the National Wildlife Refuge System. Michigan's Wildlife Division will be used as the example here.

The overall goal of the Wildlife Division is

> to protect and maintain through effective management optimum populations of all wild birds and animals for the numerous recreational, ecological, and economic benefits they afford people (Michigan DNR, 1975, p. 223).

More specifically, in regard to deer management, the goal is to

> provide increased recreational use opportunities and the economic benefits generated by increasing the deer herd population through improving the deer range carrying capacity (ibid., p. 223).

These goals present a number of questions. In particular, what is an "optimum population" and what is meant by "deer range carrying capacity"? Being a wildlife agency, it may be assumed a strict ecological

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strict ecological CC is implied, but the basic problem is an inherent assumption that the deer range carrying capacity may be determined solely on ecological grounds. Rather simple simulation experiments will show that deer populations are closely related to the character and intensity of hunting as these influence the age and sex structure of the deer population which in turn is related to food supply needs and population dynamics.[3]

There is an assumption in the goal for deer management that increasing the deer herd will generate increased benefits. This need not be the case, even if benefits are restricted to hunters alone.

Benefits to hunters and other interest groups are recognized, but the costs involved in supplying deer herd populations of a given level are not really considered. These include the costs inherent in an intensive deer management program as well as the opportunity costs of land and other resources for agriculture, timber, and other kinds of recreation. The impacts of large deer herds on agricultural crops, highway safety, vegetation, and other wildlife must also be given some consideration.

One of the most difficult tasks, given the multiple, conflicting, and vaguely defined objectives is the development of performance measures for the system. Just as the modeling of the system can lead to refinement of its definition, the process of developing performance measures can lead to refinement of objectives.

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[3]Short (1972) notes the dependence of deer CC on age and sex makeup of the herd.

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This study will begin with an assumed objective of maximizing net benefits for man (in this case limited to hunters) from the management and use of the hypothetical forest site. Thus a primary need is valid measures of hunter benefits. This will be the primary thrust of modeling efforts in Chapter 5.

This brief outline of the limits, makeup, and objectives of the DFH system provides sufficient background to proceed with more detailed modeling of the system, where the identification of the system and its objectives will be refined.

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CHAPTER 5

MODELING

The modeling phase is an integral part of the system identification. In order to model the system, variables, components, and interactions must be precisely defined. Precise definition of terms and relationships is critical to communication of ideas, results, and research problems between disciplines. Precise definition contributes to the organization and understanding of the RCC mess as well. Modeling requires that assumptions be made explicit. This is especially important in interdisciplinary research efforts as much confusion and conflict in interdisciplinary research results from disciplines working from different definitions or assumptions. Hence the model of the system is an important component in the integrative research framework.

The purpose of this chapter is to demonstrate the relationship between modeling and the integrative framework and to examine the ability of systems modeling approaches to integrate models from different disciplines. It is desired to show how the conceptual model suggests refined research problems for specific disciplines and its corresponding ability to integrate discipline specific models into its framework.

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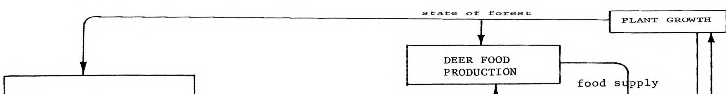
feedback of research, models, and problems between the conceptual model and individual disciplines. A general model of hunting will be developed in Section 5.3 and then specific model formulations for this study will be presented in Section 5.6. First, the overall system model and the ecosystem component will be briefly presented.

5.1 A Systems Model of the Deer-Forest-Hunter System

The initial identification of the DFH system presented in Chapter 4 provides a starting point for the modeling phase. The systems model of the CC mess is particularly appropriate as it provides a framework whereby individual interactions may be identified and specific models developed for each. Individual disciplines may tackle those interactions in which interest, expertise, or suitable theories exist for the development of analytical models of the given relationships. The overall framework provides the means for putting these disciplinary contributions together, by providing a common set of system components and variables.

Three major subsystems are under consideration here: (1) the user subsystem (hunters), (2) the resource subsystem (deer-forest ecosystem), and (3) the management subsystem. The block diagram of Figure 5.1 shows how these three submodels fit together.

The hunter model consists of two major blocks. First the deer harvest is determined based on the number of deer present and management control of the number of hunters and the kinds of deer which are vulnerable to the hunt. The second block is the model of hunter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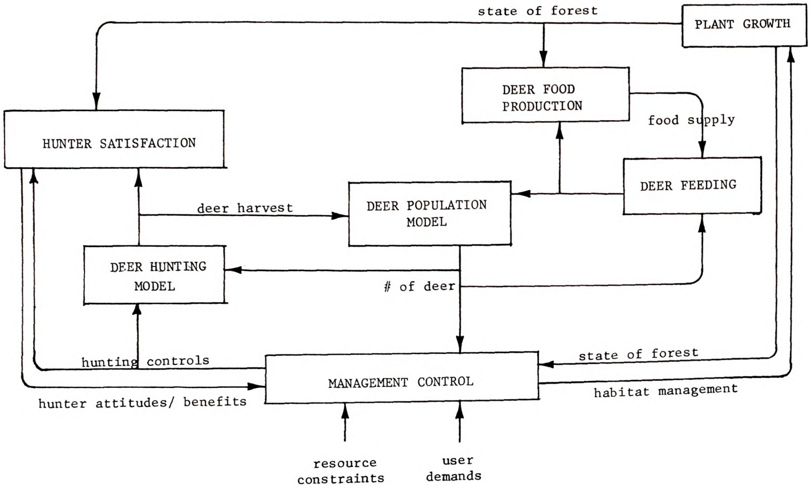

Figure 5.1 -- Block Diagram of the Deer-Forest-Hunter System

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perceptions/satisfactions/valuations[1] based on the hunting experiences in terms of success, management, and the general hunting environment. Aggregate values for hunter benefits and satisfactions are fed back to management as one of the information feedback loops.

The ecosystem model consists of the four blocks on the right hand side of Figure 5.1. The PLANT GROWTH model simulates forest successional patterns from grasses to shrubs to immature forest to mature forest. DEER FOOD PRODUCTION is based on the stage of forest growth which, in part, determines the quantity of different species and availability of food for deer. The DEER FEEDING model depletes the food supply as well as providing nourishment for the deer. The amount of feeding is based on available food supply and the number and age makeup of the deer population. The winter food intake of deer is input into the DEER POPULATION model as one of the determinants of spring birth rates. Birth rates are also dependent on herd density and age of the doe. The population model takes care of births, natural mortality, and the updating of ages each year. The details of the modeling of each of the blocks of the ecosystem model will be left to Appendix B. The behavior of the model will be demonstrated using simulation runs in Chapter 6.

The annual fall harvest of deer by hunters provides the link between the ecosystem and hunting models. The fall harvest of deer

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[1]Perceptions, satisfactions, and valuations will all be considered to be identical for modeling purposes. It is left for sociologists and psychologists to separate them as the models presented here are refined.

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supplements natural mortality rates. The number of deer affect hunter success rates and thus in turn satisfactions from hunting experiences.

The management control system consists of management aimed at hunters and management control of the resource system.[2] Resource control will be limited to simulations of clearcutting to increase food supplies and habitat for deer. Clearcuts are simulated by corresponding reductions in tree biomass. For example, a 25% clearcut is simulated by reducing trees biomass by 25%. For simplicity, the ecosystem model assumes age and density of the forest to be uniform throughout the study area.

Control of hunters takes the form of limiting the number of hunters as well as the kinds of deer which can be taken, simulating existing permit systems. In particular, the vulnerability of each age/sex class of deer may be specified. Thus, does may be excluded or partially included in the hunt. Partial inclusion is accomplished by setting vulnerabilities at levels between zero and one. A vulnerability of one for any age/sex class implies full inclusion. Vulnerabilities of .50 would only make half of that class vulnerable to the hunt. No discrimination by hunters in kills are assumed so that setting vulnerabilities of .50 for does and 1.0 for bucks would result in harvest rates of does being half that for bucks.

The management control system will be treated exogenously in a gaming format. That is, management schemes are not determined inside

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[2]The reader is referred to Strung (1973) for a layman's description of deer hunting and management. Severinghaus (1975a, 1975b) gives a similar treatment of deer ecology and management.

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the model, but are specified exogenously. Resulting effects on the system are then examined in simulation experiments. One simple type of cybernetic, self-controlling management control will be presented for illustrative purposes in Chapter 6.

Another way of looking at the system is through the real time sequence of events. The year is divided into six two-month periods starting in the spring of each year.

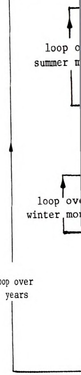
1. April-May
2. June-July
3. August-September
4. October-November
5. December-January
6. February-March.

In this way the natural processes which take place in the forest and deer populations may be broken down and simulated at the proper time. Plant production is divided into a growing season (April-September), a die down (October-November), and a winter dormant period (December-March). Deer give birth in early spring and are harvested in the fall (October-November). Figure 5.2 shows how the submodels are put together to correspond to the natural real-world sequence of events.

Given a broad perspective on the systems model, Section 5.2 proceeds with a detailed look at the modeling of the hunter subsystem. It is approached through the broad integrative framework for interdisciplinary research.

5.2 The Integrative Framework and Modeling

A comparison of the initial system identification and the existing research literature reveals a number of areas where research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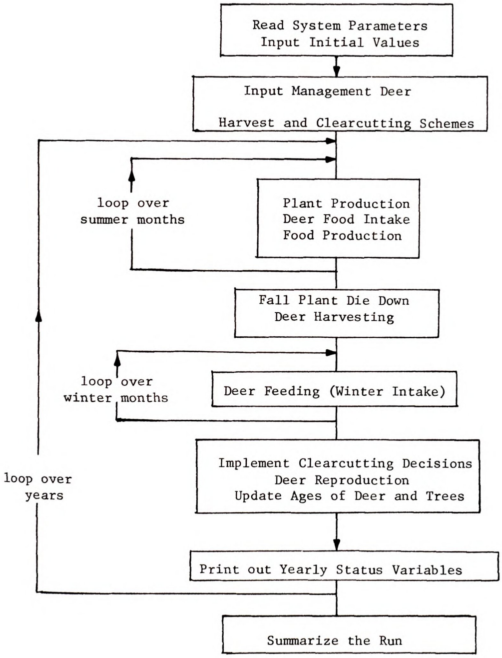

Figure 5.2 -- System Flow Chart

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and modeling are lacking. The identification of research areas is one of the early contributions of the integrative framework. Attempting to assemble a comprehensive model of the DFH system reveals gaps in knowledge, theory, and modeling. Whereas ecosystem modeling has been quite extensive, the user subsystem is relatively unknown.

In particular, little is known about what produces satisfactions or quality in hunting experiences (Hendee and Potter, 1971). The modeling of hunter behavior and valuation of hunting experiences are especially critical if one of the goals of the system is the maximization of benefits for hunters. A sound model of hunter behavior and valuation should be useful in developing valid performance measures for the system.

Previous attempts to value hunting have used days afield or game bagged to measure benefits to sportsmen. The former emphasize the recreational nature of the experience and use valuation techniques developed for recreation in general, including willingness to pay surveys (Horvath, 1974), gross expenditures (DeGraaf and Payne, 1975), and values derived from statistical demand curves using Clawson-Hotelling techniques (Jamsen and Ellefson, 1971). Game bagged approaches rely on success rates or put "shadow prices" on each deer taken in the hunt.

More often than not, these valuation procedures arrive at dollar values without shedding much light on the underlying relationships or determinants of value in sport hunting. This raises a need for a more

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This need may be directed to wildlife managers, social scientists, or resource economists in hopes of receiving contributions to the resolution and refinement of this part of the RCC problem under study. In the following section a general model of deer hunting, as might be developed by a resource economist, will be presented. It will subsequently be tailored to fit the particular problem at hand and then fitted in with the ecosystem and management subsystem models. This approach is designed to simulate the workings of the integrative model.

5.3 A General Economic Model of Deer Hunting

Although the model presented here is for deer hunting, it could also be applied to other kinds of sport hunting and fishing with a few complications, most notably the inclusion of bag limits greater than one. For deer, it is assumed unless otherwise stated that the hunt ends with a kill.

The approach taken here towards valuation and modeling differs from past work in three major respects. First, the focus is on the individual hunter, avoiding some of the problems encountered in highly aggregated approaches. The individual hunter is viewed as both producer and consumer. He produces units of hunting by combining his resources of time, equipment, knowledge, transportation, and energy with land and wildlife resources which are often publicly provided.

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Second, a dual valuation technique is used. Benefits from sport hunting are divided into two sets of interrelated values: (1) the benefits of the recreational experience not including benefits attributable to the actual bagging of game, and (2) the benefits derived from the actual taking of game. Some may question if these benefits may be separated either theoretically or operationally, but the subsequent analysis will attempt to demonstrate that such a separation yields significant dividends conceptually, in explaining hunter behavior, and operationally, for valuing hunting experiences. The third characteristic of the approach is the use of a stochastic model introducing the aspect of chance into the hunting experience.

5.3.1 The Model

Benefits from deer hunting are divided into two parts for an individual hunter: (1) $V_u(n)$ represents the marginal benefit derived from the nth unit of hunting, not including those benefits attributable to a kill, and (2) $V_s(n)$ is the marginal benefit of a kill itself, when the kill occurs during the nth unit of hunting.

Note that the product, units of hunting, is defined in terms of some unit of time spent in the activity. It is assumed that a kill in time period n cannot affect benefits derived in previous hours of hunting. Changes in benefits in a hunting experience due to a kill during the nth time period are all attributed to that period.

$V_u(n)$ is essentially the marginal benefit curve for an unsuccessful hunter and should reflect the diminishing marginal returns from additional consump

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additional consumption. If successful at any time, n, the hunter derives benefits $V_u(n) + V_s(n)$ during that period, deriving benefit $V_u(n)$ in all unsuccessful time periods. $V_s(n)$ is assumed to be greater than zero, although for certain classes of hunters an early kill may have negative value in that it excludes the hunter from further participation.

$V_u(n)$ may be postulated to be a function of n, to reflect diminishing returns, deer density to reflect values of deer sign and sightings, hunter density to reflect congestion costs, and possibly perceptions of the hunting environment to include the effects of clear-cuts and other environmental factors on hunter satisfactions.

To determine marginal benefits in any time period for a given hunter, it must be known whether or not a kill is obtained. This may be introduced by means of a probability $p(n)$ $(0 \le p(n) \le 1)$ of success in period n. This probability may be assumed constant or made a function of herd size, hunters in the field, or skill of the individual hunter. Varying $p(n)$ with herd size captures the depletion effect, while including hunter density introduces the effect of hunter density on success.

The expected marginal benefit function (EMB) is given by:

$$EMB(n) = V_u(n) + p(n) \times V_s(n) \qquad (5.1)$$

The model is simplified by assuming $p(n) = p$ and $V_s(n) = K$ are both constant, with neither the probability nor the value of a kill depending on when the deer is taken. In this case $EMB(n) = V_u(n) + p \times K$.

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Some of the measurement problems that are involved in operationalizing this model are purposely being avoided at this stage, but a few words on the measurement of costs is in order. The marginal cost curve (MC) for an individual hunter will depend on the time period used as a hunting unit. Using hours afield presents problems due to discontinuities in the marginal cost curve resulting from transportation costs at the beginning of each new day of hunting. If a fixed number of hours on each hunting occasion is assumed, days afield or hunting occasions might be used, but daily and weekend hunting trips will still involve distinct cost functions. Operationally, these problems may be dealt with by developing separate curves for different classes of trips, using averages, or aggregating.

Using a constant marginal cost curve solves most of these problems and, although unrealistic, may be justifiable depending on the purposes of the model. For now, an increasing marginal cost function will be assumed to reflect the greater likelihood that working days or other opportunities are being foregone for additional hunting as the number of days hunted increases.

5.3.2 Determination of the Optimal Production Point

Given the marginal benefit and cost curves as described above, the standard marginal analysis may be applied to determine the optimal point of production from the individual hunter's standpoint. That is, how long should an unsuccessful hunter remain afield? The hunter should continue as long as his expected marginal benefits exceed his marginal costs. Figure 5.

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costs. Figure 5.3 shows the marginal benefit and cost curves assuming $p(n) = p$ and $V_s(n) = K$ are both constant. The hunter should discontinue his hunt at the point Q if he does not bag a deer before that time. Q is the quitting point.

In effect, the hunt is treated as a gamble, where the wager is the marginal cost of an additional unit of hunting and the payoff is $V_u + K$ or V_u depending on whether or not the hunter is successful. Each additional hunting period is treated as another flip of a coin with probability p(n) of success on the nth flip. Determining how long to hunt is equivalent to ascertaining when the hunter should stop gambling.

The points where the marginal cost curve, MC(n), intersects the three marginal benefit curves (V_u, $V_u + pK$, and $V_u + K$) divide the figure into four zones as follows:

1. CAN'T LOSE ZONE OA. Here $V_u > MC$ and benefits exceed costs, win or lose.

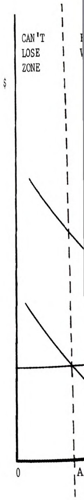
2. GAMBLING ZONE AB. This is divided into two regions by the point Q.

   2a. EXPECTED WIN ZONE AQ--where $V_u + pK > MC$.

   2b. EXPECTED LOSE ZONE QB--where $V_u + pK < MC$.

3. CAN'T WIN ZONE BC. For $n > B$, $V_u + K < MC$ and the hunter has a net loss even if he is successful.

Note that the hunter may actually hunt in those portions of the curve where benefits from the experience are less than marginal costs, and even where $V_u(n)$ is negative. Hunters remain afield in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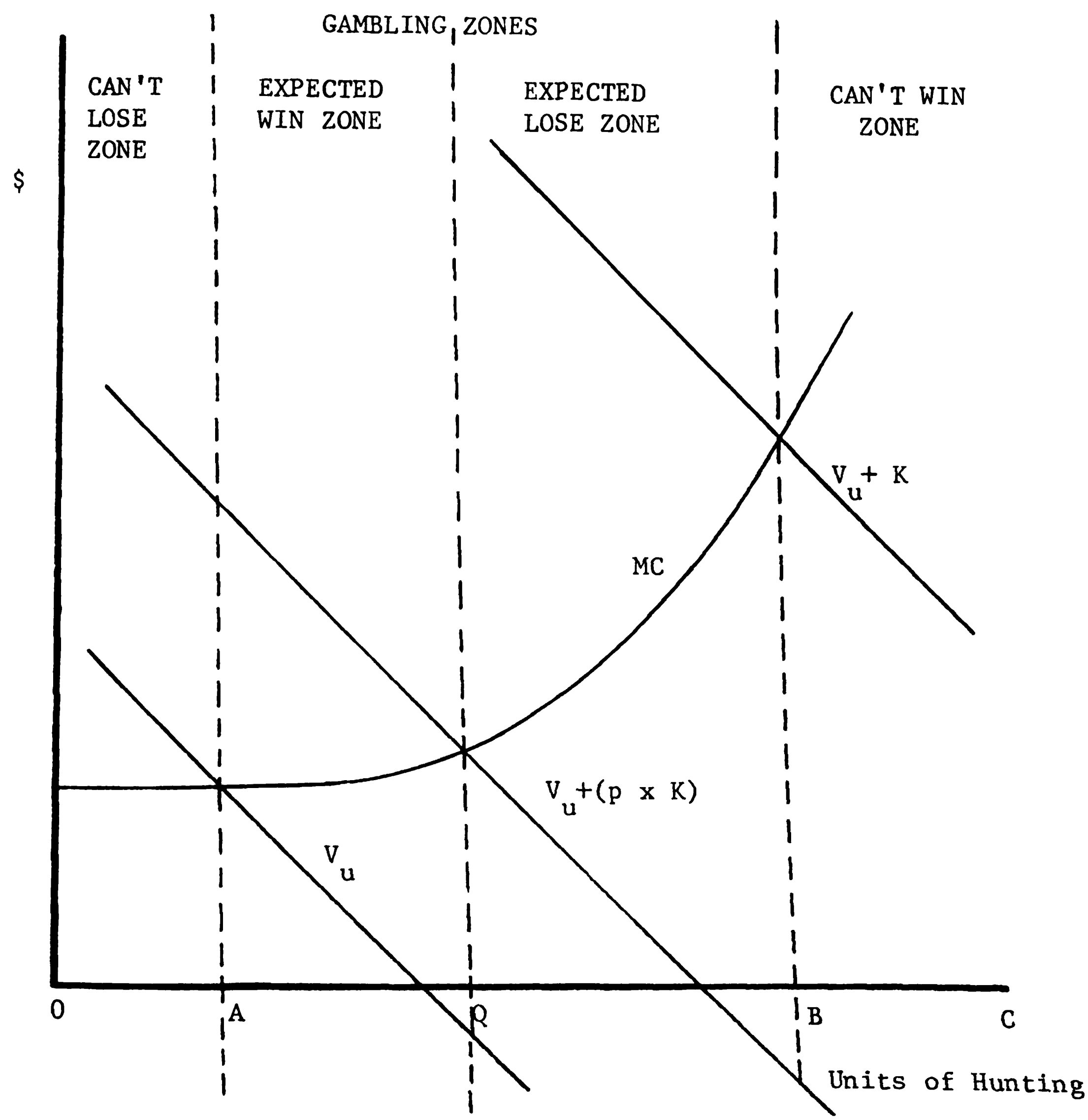

Figure 5.3 -- The Hunting Model

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hopes of capturing the big payoff associated with the kill. Here it is assumed that there are no positive or negative values associated with the act of gambling itself. A parameter could be introduced into the decision on the quitting point to represent the hunter's tendency to gamble.

5.3.3 Including Depletion Externalities

Depletion externalities in hunting may be included in the model by simply letting p(n) be a function of the deer herd size. As the hunting season progresses the herd decreases with each successful kill, thus reducing the probability of success for those hunters remaining. Probabilities also appear to decrease due to the selectivity of early kills and increased deer wariness later in the season (Kooiker, 1972).

Assuming the probability of a kill decreases with n, the expected marginal benefit curve $V_u(n) + p(n) \times K$ will approach $V_u(n)$ as n increases and p(n) approaches zero. This is shown in Figure 5.4. If p_o denotes the probability of success on opening day, then the shaded area between the curves $V_u + p_oK$ and $V_u + p(n)K$ is a rough measure of the expected loss in benefits per hunter due to the depletion externality imposed by the success and effort of all other hunters.

5.3.4 Importance of p

In the long run, the individual hunter will maximize his expected net returns if he continues to hunt out to the quitting point Q when unsuccessful. The probability p(n) is a key parameter


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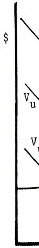
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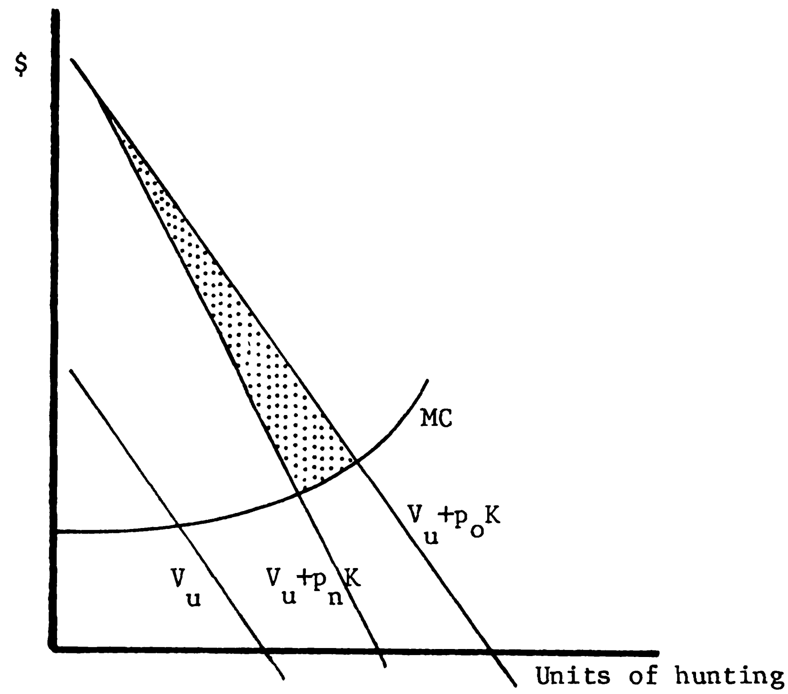
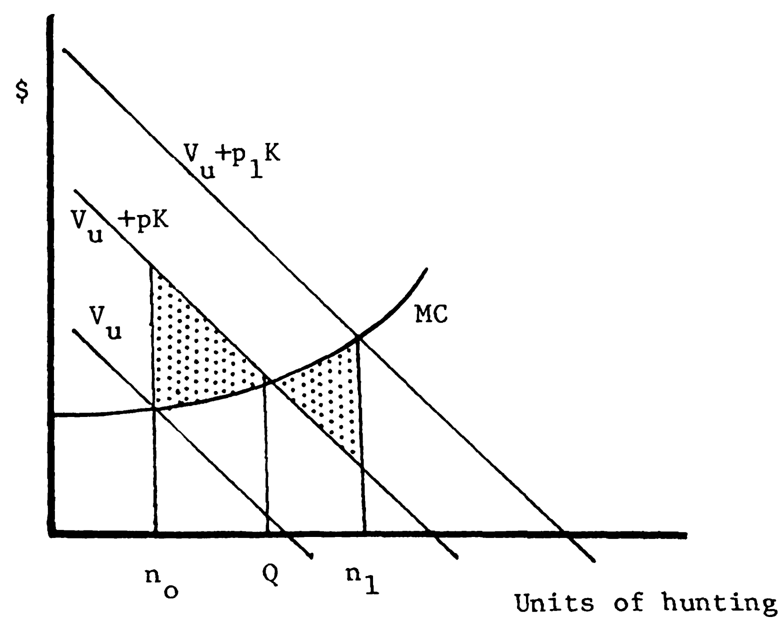


Figure 5.4 -- Depletion Externalities



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Most models of economic man assume complete knowledge. Hunters seldom have accurate information regarding their chances of success. Probabilities can only be estimated from other hunter's successes, deer sign and sightings, and reports of wildlife agencies.

Figure 5.5 shows the affects of a hunter over- or under-estimating his chances of a kill. If he underestimates p, say assuming $p_o < p$, he will estimate his expected benefits along curve $V_u + p_oK$ instead of $V_u + pK$. This will result in an early curtailment of an unsuccessful hunt as the perceived quitting point n_o will be to the left of Q.

Similarly, if the probability is overestimated to be $p_1 > p$, the hunter will remain afield too long, to n_1 instead of Q. In either case, there will be an expected net loss of benefits in the long run due to opportunities that are not taken or overconsumption. The shaded areas may be interpreted as measures of the expected value of accurate information about p to the hunter, as they represent the expected net losses due to the misinformation.

Figure 5.5 may also be used to show the different values associated with hunting at areas with different success rates. If p_o, p, and p_1 are interpreted as actual probabilities of success at three distinct hunting areas, the three expected marginal benefit curves reflect the difference in values of these three sites for an individual hunter

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individual hunter. By aggregating individual benefits over all hunters using the area, a measure of the value of the area for hunting may be derived. Values associated with high density deer areas will be even greater if the value of deer sightings and sign is incorporated in the marginal benefit curve V_u.

5.4 Valuation of Hunting Areas by Aggregating Individual Benefits

Focusing on the individual hunter has shed considerable light on hunter behavior and individual valuation of hunting experiences. To arrive at values for hunting areas themselves, the focus shifts to the viewpoint of land and wildlife management agencies, and values are derived for hunting areas based on the benefits they generate for hunting. It is assumed that an appropriate measure of value is the expected total benefits (net of costs incurred by hunters) for all hunters on the area. Management costs will not be included here.

The aggregation process is straightforward and is only complicated by the need to keep track of which hunters are still in the field and which are successful. NH hunters are assumed to start on opening day and continue hunting until their individual quitting points Q_i are reached.[3] Further, it is assumed that hunters

[3]These assumptions may be dropped with the addition of considerable bookkeeping to keep track of when individual hunters are afield. The assumption that the hunt ends with a kill may also be relaxed by allowing successful hunters to continue hunting to collect V_u benefits until $V_u = MC$.

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possess complete knowledge of their individual probabilities of success $p^i(n)$.

First, it will be shown how values for hunting areas may be derived treating each hunter as an individual. Then the procedure will be simplified by grouping hunters into distinct classes based on their valuation functions.

Individual Valuation

Each individual hunter i ($i = i, \ldots NH$) is assumed to have a distinct benefit and cost function V_u^i, V_s^i, and MC^i and distinct probabilities p^i. To determine total benefits and costs generated in any time period n, it must be known how many hunters are afield and which hunters are successful. If simulating, harvested deer and successful hunters would be removed from the system at the end of each period and the values of V_u, V_s, and p adjusted accordingly for the next period. U(n) will denote the set of hunters still afield in period n.

Successes are generated by assuming independent trials and using random variables x_n^i which take on the value one for success with probability $p^i(n)$ and the value zero for failure with probability $1 - p^i(n)$. Then the total marginal benefits and costs generated in period n are given by

$$MB(n) = \sum_{\substack{i=1 \\ i \in U(n)}}^{NH} \left[V_u^i(n) + x_n^i \, V_s^i(n) \right] \qquad MC(n) = \sum_{\substack{i=1 \\ i \in U(n)}}^{NH} MC^i(n) \tag{5.2}$$

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where the sum is over those hunters i in the set U(n) consisting of hunters unsuccessful up to period n and with individual quitting points $Q^i > n$. Total benefits and costs may be obtained by summing the marginal values out to the point where U(n) is empty. A value of the hunting area could be obtained by taking the difference of the resulting total benefits and costs.

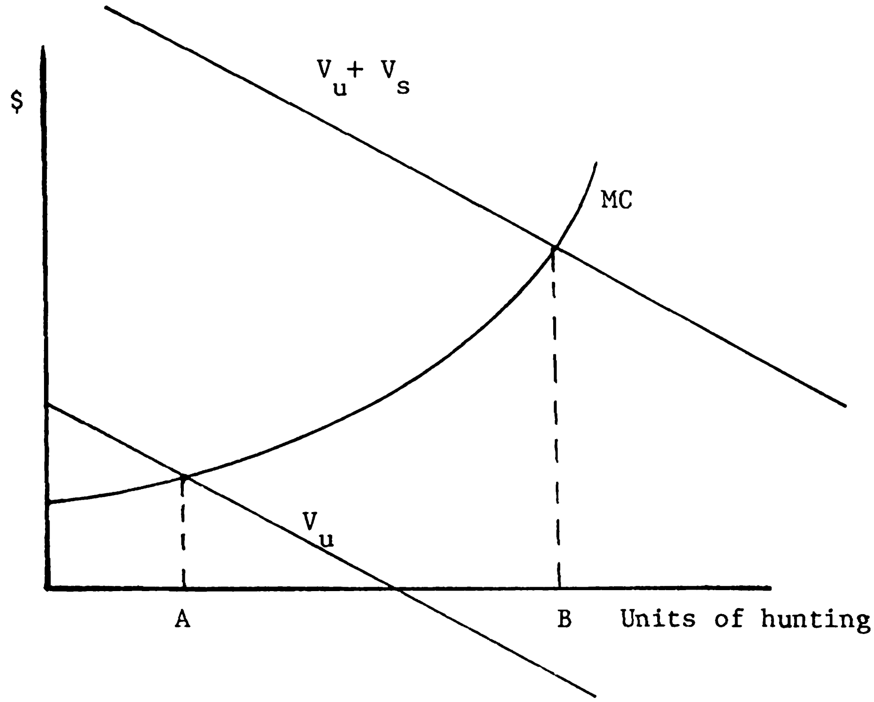
Valuation with Groups of Hunters

The calculations may be simplified by assuming all hunters have the same probabilities of success and identical marginal benefit and cost curves. More realistically a finite number of groups of hunters might be assumed to exist with all hunters in the same group sharing a set of benefit, cost, and probability functions.

An example of such a classification is shown in Figure 5.6. The two groups of hunters, labeled MEAT and EXPERIENCE hunters are separated based on the relative magnitudes of V_u and V_s. The MEAT group puts primary importance on the kill and little on the experience itself, while the EXPERIENCE hunters are relatively uninfluenced by the likelihood of a kill. These curves are meant to represent two extremes of hunters.

The separation of these hunters is based on the valuation functions, but the nature of these differences has significant implications for management. Note that the gambling zone AB for the MEAT hunter is very large, whereas the EXPERIENCE hunter's is relatively small. Hence the higher value placed on the kill, the larger the

MEAT HUNTERS



EXPERIENCE HUNTERS

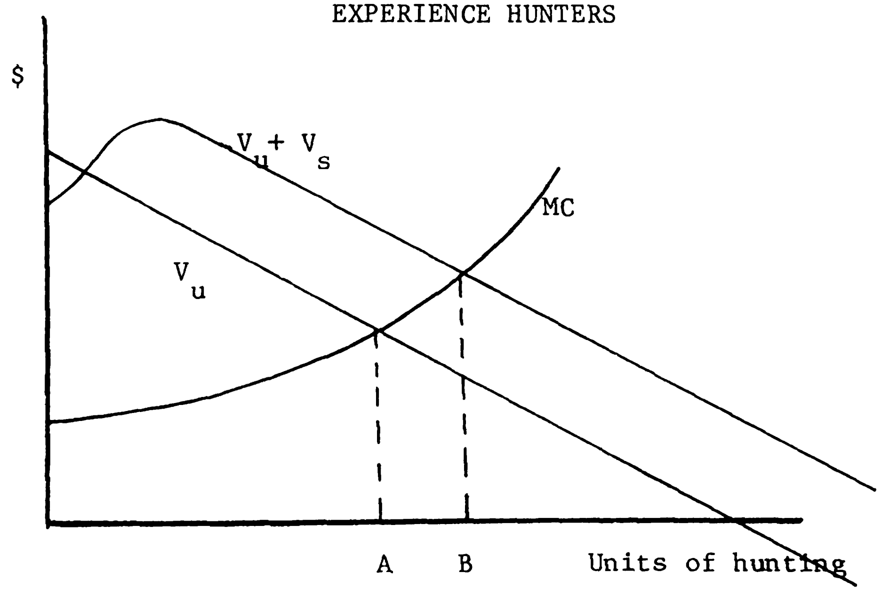


Figure 5.6 -- Classifying Hunters

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gambling area. Also most of the benefits generated from the MEAT group are from kills while the EXPERIENCE group accumulates benefits primarily from the hunting experience itself. Thus the MEAT group will be much more sensitive to the value of p, while the EXPERIENCE group may be more sensitive to congestion, clearcuts, or other environmental factors.

With this example in mind, let hunters be partitioned into G groups with functions p^i, V_u^i, V_s^i, and MC^i, $i = 1, \ldots G$. Let $NH^i(n)$ denote the number of hunters remaining in the field at time n from group i. Now rather than generating individual random variables for each hunter, one can use random variables x_n^i for the number of successes in group i at time period n. A binomial distribution with $NH^i(n)$ trials and probability $p^i(n)$ on each trial is assumed. For large $NH^i(n)$ and small $p^i(n)$, a Poisson distribution may be used to approximate the binomial.[4] Marginal benefits and costs generated in period n within group i are given by

$$TMB^i(n) = NH^i(n)\ V_u^i(n) + x_n^i\ V_s^i(n) \qquad TMC^i(n) = NH^i(n)\ MC^i(n)$$

As above, successful hunters in each group are removed from the hunt by making $NH^i(n+1) = NH^i(n) - x_n^i$. All unsuccessful hunters in each group are removed once the group quitting point Q^i is reached.

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[4]See Freund (1962, p. 72) for a discussion of the Poisson distribution and its use in approximating the binomial.

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The total net benefits from the site are obtained by summing over all groups of hunters out to the respective quitting points.

$$\text{Total net benefits} = \sum_{i=1}^{G} \sum_{n=1}^{Q^i} \left[TMB^i(n) - TMC^i(n) \right]$$

$$= \sum_{i=1}^{G} \sum_{n=1}^{Q^i} \left[NH^i(n) \ (V_u^i(n) - MC^i(n)) + x_n^i \ V_s^i(n) \right] \tag{5.3}$$

Due to the presence of the random variables x_n^i, this total net benefit is itself a random variable. Its expected value could be obtained by Monte Carlo simulation techniques. If all of the functions involved are reasonably well behaved, replacing x_n^i by its expected value $NH^i(n) \times p^i(n)$ should give reasonable approximations to the expected total net benefits of the site for hunting. Given the precision in determination of the hunting valuation functions, replacing random variables by their expected values appears to be a reasonable simplification of the valuation procedure. It of course changes the model from a stochastic one to a deterministic one.

5.5 The Integrative Model Revisited

The economic model presented in the preceding section adds a new dimension to deer hunting. The economic view is quite distinct from that of wildlife managers or even hunters themselves. The contribution it can make to wildlife management and, more specifically, the understanding of the DFH system remains to be demonstrated.

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The model raises serious questions about the validity of the traditional measures of value in hunting. In particular, it points out the neglect of diminishing returns and the "gambling nature" of hunting. It suggests that some hunting experiences may generate negative benefits and simple measures of days afield or success rates may not be adequate surrogates for hunting values.

The disparities between past approaches to hunting and the economic model should generate considerable debate among researchers from different disciplines as to which models more accurately describe the real world system. This raises a number of research areas.

The model provides a framework for asking the relevant research questions. Being an economic model (in many ways like Fischer and Krutilla's, 1972), the model skips over more detailed treatments of perception of the environment and hunter-hunter interactions, passing directly from experience to valuation. Sociologists and psychologists can make a contribution in filling in this gap, possibly adding some measure of satisfaction intermediate between perception and valuation. These social scientists may also be better equipped to identify the distinctions between experience and kill, possibly identifying the components of the experience in more detail.

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Work is also needed on measurement of hunter knowledge and expectations and how this information determines the selection of a site for hunting. This could be useful in developing an allocation model as well as a model to estimate demand for hunting.

The economic model raises a number of measurement questions. Can measures be developed to separate experience benefits from kill benefits? What are the shapes of the curves V_u, V_s, p, and MC, and what are the major independent variables for each function? What is the contribution of diminishing returns, deer and hunter densities, and possibly other environmental, social, and psychological variables on hunting satisfaction? Can hunters be classified into meaningful groups based on their valuation functions? A great deal of research on these and other questions raised by the model is needed before meaningful values of lands for hunting can be derived.

The model points out a rather typical problem of recreation research. Most of the work to date has been aimed at finding out which variables are related. There have been very few efforts that begin to examine exactly what the identified relationships are in terms of precise functional relationships. Attempts to value hunting experiences require information on how much congestion, deer sightings, a kill, the forest environment, and other factors contribute to the value of a hunting experience. These are the kind of precise mathematical relationships required by a simulation model.

One contribution of the model is in providing a possible performance measure for the system. Management aimed at maximizing

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benefits to hunters will require a measure of benefits derived under alternative management schemes. The measures of value for hunting areas derived in the previous section are potential candidates for such a performance measure. The total net benefits measure of equation 5.3 with x_n^i replaced by its expected value will be used in Chapter 6 as a performance measure for simulation experiments. Other potential performance measures which can be generated by the model include more traditional measures of days afield, success rate, and harvest rate.

First, more precise functional relationships must be specified for the valuation functions and the hunting model. This is the task of the next section where the general economic model will be precisely specified for the DFH system under study.

5.6 The Specific Hunter Subsystem Model

The general economic model of deer hunting presents four functions which must be specified before hunter behavior and valuation can be simulated. These are (1) V_u, the marginal benefit function associated with just the experience; (2) V_s, the benefit derived from a kill; (3) p, the probability of a kill; and (4) MC, the marginal cost function.

Sufficient research and data gathering has not been carried out to confidently identify these functional relationships and calibrate them, but by making a set of reasonable assumptions about the independent variables and hunter's behavior and valuation, a beginning can be made.

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By setting down a set of specific hypothesized relationships and specific functional forms, testable research hypotheses will be generated and some insights into the nature of hunting behavior may be revealed. In keeping with existing knowledge of deer-forest-hunter systems, the models will be kept simple and parameters will be inserted freely. Alternative models will be presented for each of the four functional relationships with the simpler relationship being used in subsequent simulation experiments. More complex models are discussed to indicate directions for research and the iterative model refinement process.

There are three key assumptions of the general hunting model.

1. Benefits attributable to the kill may be separated from those attributed to the hunting experience.
2. Hunters make decisions on how long to hunt by weighing their expected returns and costs. Each additional unit of hunting is treated independently and marginal benefits and costs are considered in making decisions on when to quit hunting.
3. Benefits from hunting experiences exhibit diminishing returns with added units of consumption within a given hunting season.

For now it is further assumed that all hunters under consideration form a single class with uniform valuations and behavior. Further assumptions will be added as each function is discussed in turn.

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V_u: Benefits from the Experience

The marginal benefit from the experience is assumed to be a function of the amount of consumption to date (n), deer sightings (DEERSEEN), perceived congestion (CONG), and perceptions of the forest environment (FORCHAR). Simple measures of each of these independent variables will be discussed shortly.

First, the basic diminishing returns model for V_u will be introduced. It is assumed that marginal benefits associated with hunting experiences drop off linearly with consumption.

$$V_u(n) = C_o + C_1 \times n \tag{1}$$

where n represents the nth unit of consumption and C_o and C_1 are parameters representing the benefits from the first unit and the decrease in benefits from each additional unit, respectively.

This simple model may be expanded to include quality factors in hunting experiences measured by the other three independent variables. Quality factors will be treated as shifters of C_o and will be assumed independent of C_1. The contribution to value of each quality factor may be measured by considering deviations from "ideal" conditions, with C_o in equation (1) representing ideal conditions.

Research to date has not clearly identified what "ideal" conditions are for deer hunting, or to what degree these may differ from hunter to hunter, but for illustrative purposes such a model will provide a good s

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provide a good starting point to the inclusion of quality factors in hunting valuation.[5]

Letting the subscript ID denote the ideal level of each variable, C_o might be assumed to be a linear combination of three quality variables as follows:

$$C_o = C_o^* + C_2|CONG-CONG_{ID}| + C_3|DEERSEEN-DEERSEEN_{ID}| + C_4|FORCHAR-FORCHAR_{ID}| \quad (1A)$$

where C_o^* is the benefit derived from the first unit of hunting under ideal conditions, and C_2, C_3, and C_4 are weighting parameters for each of the quality variables indicating how much a deviation from the ideal, in each, shifts the valuation function. (Vertical bars represent absolute values.)

Threshold functions, logistic curves, and other non-linear relationships may be more appropriate than the above simple linear combinations, but equation (1A) should suffice to indicate possible directions for the inclusion of quality factors in the valuation function. Equation (1A) assumes that the quality factors operate independently and additively, which may also be a poor assumption. A multiplicative relationship between the quality factors might prove more realistic as any single quality factor which deviates substantially from the ideal might make the value of the experience close to zero regardless of the levels of other quality variables. Notice that the

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[5]See Peterson (1974) for a more elaborate treatment of the evaluation of quality in natural environments based on deviations between desired, actual, and perceived magnitudes of specified environmental variables.

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Measures of CONG, DEERSEEN, and FORCHAR will be merely suggested as these quality considerations are being discussed mainly to indicate research directions, not to suggest answers. CONG could be measured by simple densities of deer hunters. DEERSEEN could be measured by simple counts of deer sighted. This could be modeled using the same format as for the probability of a kill, discussed below. If it is assumed that for each M deer seen, one is killed, then the probability p of a kill multiplied by M gives the expected number of sightings.

FORCHAR might include a variety of factors. One quality factor to be considered later is clearcuts. The contribution of clearcuts to diminishing forest aesthetic qualities might be included by letting FORCHAR be a weighted sum of clearcuts, with heavier weights being assigned to larger and more recent cuts. In this way, the benefits of clearcutting in increasing deer herds could be weighed against the negative visual effects to deer hunters and others.

These quality factors will not be pursued further in this study, but are included to stimulate research and demonstrate how such research might contribute to the basic model presented here.

MC, The Marginal Cost Function

The simplest assumption for the marginal cost function is that it is a constant.

$$MC = M_c, \text{ a constant} \tag{2}$$

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Such an assumption allows data on average expenditures of hunters to be used to determine the value of M_c, the cost of a day of hunting.

Realistically, costs will vary considerably from hunter to hunter and from one hunting occasion to another. Costs will vary with the distance traveled and the duration of the hunting trip. An allocation model would be required to include differences in travel distance. Here it is assumed that all hunters come from a common origin and incur the same costs. Under these assumptions the constant marginal cost assumption is more reasonable.

One factor possibly contributing to an increasing marginal cost function is the limitation in leisure time. It might be hypothesized that as more days of hunting are consumed by a given hunter, the likelihood of sacrificing days of work increases. Relating days of work to days hunted would give some indication of the extent of this factor. These again are questions for further research.

p: The Probability of a Kill

The probability p of a kill for an individual hunter on a given hunting occasion is assumed to be a function of deer density and previous hunting effort. The probability of a success is clearly related to the ability to find deer which should be dependent on deer densities. Empirical data appear to indicate that another factor is at work. As the hunting season progresses, kills decrease even to a greater extent than would be indicated by decreased hunting effort or herd depletion. This is often attributed to a factor termed "deer wariness." Part of this is the selectivity of deer kills. Those deer least able to evade hunters are kil

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hunters are killed first, so that as the season progresses the overall ability of those deer remaining to evade hunters increases.

A number of other potential contributors to success in the hunt will not be considered here. These include hunter skills, the effect of hunter density in "moving the herd," and the contribution of terrain, weather, and the character of the forest (maybe the size of openings).

The hypothesized relationship is

$$p = B_1 \times \frac{\frac{NDVUL}{AREA}}{1 + B_2 \times E} \tag{3A}$$

where NDVUL is the number of deer vulnerable to the hunt, AREA is the area of the site, E is a measure of previous hunting effort, and B_1 and B_2 are parameters to be determined. The effect of "deer wariness" may be omitted by setting $B_2 = 0$ and letting

$$p = B_1 \times \frac{NDVUL}{AREA} \tag{3}$$

Data to calibrate equation (3) is more available as data on hunting effort by day of the season is not strictly needed to calibrate equation (3) whereas it is rather critical for equation (3A).

V_s: The Value of a Kill

Again, the simplest relationship is obtained by assuming that the value of a kill is independent of when the deer is taken and other factors.

$$V_s = \text{VKILL, a constant} \tag{4}$$

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Existing data would seem to dictate the use of this simplifying assumption, but a few alternatives might be profitably explored.

More generally one might assume that the value of a kill is related to the overall success rate. This is based on the hypothesis that the scarcer the product (deer kills) the greater its value. If one allows the value V_s of a kill to vary with the overall probability of getting a kill, measured by p, the question then becomes how does the value of a success vary with its likelihood. The fact that V_s should be inversely related to p seems clear from simple relationships between scarcity and value. However, how much V_s changes with p will determine whether or not greater revenues are generated by maintaining larger deer herds through intensive habitat management.

The concept of elasticity from economics is useful here. The expected (kill) benefit per hunter is obtained by multiplying his probability of success times the value associated with a success ($p \times V_s$). Equations (4A) and (4B) show two alternative models for V_s and the corresponding expected benefits and elasticities.

Function	Expected Benefits	Elasticity	
$V_s = C/p$	$EB_A = C$	$e_A = -1$	(4A)
$V_s = C \times (1-p)/p$	$EB_B = C \times (1-p)$	$e_B = -1/(1-p) \leq -1$	(4B)

Even though V_s decreases with increasing p, the expected benefits ($p \times V_s$) may increase, decrease, or remain the same, depending on the probability elasticity of V_s. In equation (4A) an elasticity of -1 indicates that expected benefits per hunter remain constant regardless of t

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regardless of the value of p. In equation (4B) expected benefits decrease as p increases since the elasticity is always less than one in absolute value. The case of equation (4), V_s = VKILL, yields increasing expected returns with increasing probabilities of success.

While this discussion may seem somewhat tangential, it should now be clear that measurement of the valuation functions, including V_s, is critical in determining appropriate management strategies and CCs for deer and hunters. The elasticity of the V_s curve will dictate what herd size or probability of success is consistent with maximizing benefits from kills. If hunter's valuation of a kill approaches equation (4B), increasing the number of deer will actually decrease benefits from kills.

A further application and extension of the above two models would be to examine variation in values placed on does, bucks, and trophy bucks. One might speculate that differences in values of bagging each of these deer are associated with differences in the scarcity of each deer class. By relating corresponding numbers of each deer class with values placed on them by hunters, one might attempt to test and calibrate equations like (4A) and (4B).

5.7 A Few Notes on Data Needs and Calibration

This dissertation is not a data-based study and little mention has been made so far of data needs or calibration of the models. The model must, of course, be tied to the real world system by means of empirical data. The emphasis here, however, is on model development prior to data c

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prior to data collection. This follows the scientific method of proceeding from hypotheses to tests of hypotheses.

Detailed discussions of calibration techniques and existing data bases will be avoided here in favor of indicating the role of the proposed research framework in directing data gathering efforts.

One obvious advantage of the comprehensive systems framework is that data gathering efforts may be organized so that the same data set may be applied to a wide variety of research efforts. At a coarse level, the variables identified in the block diagram of Figure 5.1 as being outputs of one block and inputs to other blocks can be used in calibrating a number of models. Thus data on deer populations can be used to calibrate the population, feeding, and hunting models. By considering the precise data needs of each of these models in advance, a single data gathering effort may be developed to satisfy each of the submodels.

An advantage of the systems approach is that individual submodels may be broken out and calibrated individually. This is the role of the individual disciplines. Then calibration may be refined by combining the individual models and examining their behavior in the total system. Such combined simulation runs provide checks on the internal consistency of the models as well as the data used to calibrate them. Those parts of the model in which a great deal of confidence exists can be helpful in calibrating and refining less well developed parts of the model or models for which direct data gathering is difficult. Some of these principles will be demonstrated in Chapter 6 wh

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Data needs of simulation models are generally both precise and flexible. On the one hand, if rigorous data fitting techniques are to be used, the models generally have rather precise data needs. On the other hand, when such precise data does not exist, other ad hoc and heuristic techniques of estimating parameters are possible with simulation. The general procedure is to apply tested regression techniques to model components where possible and use ad hoc techniques to set the remaining parameters. Interactions between model components in the system as a whole provide one means of validating such calibration techniques.[6]

This advantage of simulation is especially helpful in studying messes and RCC in particular, where information and data bases vary considerably in quality and quantity. A particular problem for simulation modeling both in recreation and elsewhere is that data is too highly aggregated, both spatially and temporally. This problem occurs in attempting to calibrate the hunting model (equation (4) and (4A)). These models require data on deer density, hunting effort, and kills by day of the hunting season to determine parameters B_1 and B_2. Given such data for a sample of hunting areas, regression techniques could be used. However, except for special deer study areas, breakdowns of deer populations or hunting effort for small spatial units is lacking, and

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[6] Emshoff and Sisson (1970) present general treatments of parameter estimation and model validation for simulation models.

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data by day of the hunting season is even scarcer. Equation (4) does not require the temporal breakdown of effort and kills that equation (4A) does. Thus, in some cases the choice of the model may be dictated by existing data bases.

The estimation of parameters in the valuation function presents difficult problems for research. The traditional approaches to valuation discussed earlier all provide some information, but data gathered in willingness to pay surveys and expenditure studies is not directly applicable to the diminishing returns model for valuation of experiences or to separating kill benefits from experience benefits. Ad hoc techniques could be used to set "ballpark figures" for valuation parameters based on existing data; but ideally, new surveys should be developed to satisfy the needs of the models presented here.

A number of possibilities exist for separating kill from experience values. Surveys could be conducted requesting hunters to estimate values of their hunting experiences. Then responses of successful and unsuccessful hunters could be compared and differences attributed to the value of getting a kill. An alternative measure would be to simply ask hunters what value they place on getting a deer. Another alternative would be to explore the relationship between value of a kill and scarcity as discussed in relation to equations (4A) and (4B) above.

Valuation of the experience itself could also be explored using survey methods, however, simulation techniques present opportunities for checking the consistency of hunter responses to survey questions and actual beha

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CHAPTER 6

SIMULATION EXPERIMENTS

This chapter will examine the role of simulation in the integrative research framework for recreation. Simulation adds an additional dimension to the research framework beyond the contribution of modeling itself, and it is for this reason that simulation techniques are a key component of the set of meta-tools.

Simulation allows the researcher to experiment with the model and examine its behavior under a variety of inputs and system designs. These experiments give the researcher a better understanding of the model itself, and hopefully the real-world system it purports to represent.

Simulation experiments may serve a number of purposes in the research process including the following:

1. Sensitivity analysis
2. Making qualitative inferences about system behavior
3. Setting parameters
4. Testing alternative model formulations and system components
5. Examining long- and short-term impacts on management strategies
6. Refining data needs

This study is concerned with CC, so a primary interest is the behavior of the system under alternative stocking levels for deer and deer hunters. Howev

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hunters. However, as pointed out earlier, CC cannot be limited to simple use questions. Almost all of the problems and decisions confronting resource managers are in some way related to the determination of appropriate use levels. For this reason a model which allows managers and researchers to explore many phases of recreation resource management should be more enlightening than one which determines "optimal use levels" based on a limited set of considerations.

The primary utilization of simulation here is in its contribution to the research process. The role of simulation in organizing and directing research has not been well recognized in recreation.[1] A dangerous and all too prevalent tendency is to proceed to use simulation models for policy analysis before models are adequately tested or developed. The model developed in Chapter 5 is flexible enough to simulate almost any real world policy for deer or hunter management, but the model has not been designed for that purpose. It was purposely designed to be general, not to fit any real world system, and has not been calibrated to fit any real world system. There is no intent to use the model for policy analysis, although it can be used to illustrate how simulation models can be used for such purposes.

The numbers generated in the following simulations have little meaning and do not purport to say anything about deer or hunters. The purpose here is to demonstrate the role of simulation in the research framework for RCC. In particular, the use of simulation to refine earlier steps in the systems approach and to raise questions for

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[1]Cesario (1975) has recently noted the possible uses of simulation in recreation planning and policy analysis.

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Part of the contribution to this understanding is the illustration of some of the components and dimensions of RCC identified earlier. These include dynamics, tradeoffs, and the role of objectives and management controls in the setting of CCs.

The simulation experiments will begin with the hunter subsystem model treated by itself. One advantage of simulation modeling techniques is that individual blocks may be analyzed by themselves, or in regard to the interaction with the entire system. Section 6.1 will examine the hunter model by itself, ignoring its relationship to the ecosystem and deer populations in particular. Deer population and hunting effort will be treated exogenously and a single hunting season will be examined. The experiments on the hunter model are designed to examine the behavior of the "gambling model" of deer hunting and to explore feasible values for parameters in the hunting and valuation blocks.

Section 6.2 will proceed to link the hunter model to an ecosystem model. Long-term impacts and behavioral characteristics of the model will be examined. Potential use of the model for policy analysis will be shown, but the principal emphasis is on the contribution of simulation experiments to the integrative research framework by refining earlier parts of this application and suggesting directions for research. Potential contributions of simulation to system identification, goal refinement, development of performance measures, modeling, and the generat

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6.1 Experiments on the Basic Hunter Subsystem Model

In this section the behavior of the basic hunter model will be examined. This includes the hunting and valuation components. Equations 1-4 of Section 5.6 will be used in all subsequent simulation runs. The parameter B_1 of equation 3 will be set to .001 so that a huntable deer density of 20 deer per 10 square mile area results in a per hunter per day probability of a kill of .02. This would yield success rates of near 10% for hunters who spend five days in the field.

Alternative model formulations 1A, 3A, 4A, and 4B will not be considered in demonstration simulation runs as insufficient data exists to even set "ballpark figures" for the relevant parameters in these models. It will be assumed that the quality factors in equation 1A and the deer wariness factor in equation 3A contribute insignificantly to these models.

The primary emphasis here will be on examining the parameters C_o, C_1, and VKILL of the valuation functions. Recall that C_o is the benefit derived from the first day of hunting and C_1 is the drop off in benefits for each additional day. VKILL is the value of a kill. Subsequent analysis will explore the use of simulation in examining the effect of the valuation function, and deer and hunter stocking on selected system performance measures over a given hunting season. A two-week hunting season is assumed, although this is compressed into a much shorter

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6.1.1 Setting Valuation Model Parameters

One use of simulation in the research process is to explore possible settings of parameters and to examine the sensitivity of performance measures to changes in these parameters. Such analyses are especially useful where adequate knowledge to set parameter values is lacking, as it helps to identify the key parameters which must be determined and gives an estimate of the value of different degrees of accuracy in these parameters in terms of system performance measures.

As noted previously, the parameters C_o, C_1, and VKILL in the hunting valuation model are relatively unknown, and past attempts to value hunting experiences come from a wide range of sources and differ significantly. Horvath's (1974) economic survey of southeastern sportsmen estimated the average value of a day of big game hunting (mostly deer) to be \$60.86, however, the median value was only \$25.00. It is unclear whether these values represent the value of the first day of hunting, the second, or an average day. Diminishing returns are not considered and the values are not related to success rates.

The gambling model of deer hunting presented in Chapter 3 offers an opportunity to explore a number of possible valuation functions. To illustrate the use of sensitivity analysis, 80 hunters and 20 deer were input to the hypothetical DFH system. Table 6.1 shows the values of a number of performance measures generated for selected

Table 6.1 Sens
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C_o	C_1	VKI
50	-10	10
		30
		50
	-15	1
		3
		5
	-20	1
		3
		5
75	-10	1
		3
		5
	-15	1
	-20	
100	-10	
	-15	
	-20	

VKILL = value
QP = quitt
SR = succe
HR = harve

Table 6.1 Sensitivity Analysis of Valuation Function Parameters (80 hunters; 20 deer)

C_o	C_1	VKILL	QP	SR	HR	DAF	TBE/DAF ($/day)	TBK/DAF ($/day)	TB/DAF ($/day)	TB ($)
50	-10	100	3.5	.05	.21	234	15.1	1.8	16.9	3,972
		300	4.0	.06	.24	272	12.7	5.3	18.0	4,907
		500	4.5	.07	.27	309	10.2	8.7	19.0	5,880
	-15	100	3.0	.05	.18	196	13.9	1.8	15.7	3,088
		300	3.0	.05	.18	196	13.9	5.5	19.4	3,813
		500	3.0	.05	.18	196	13.9	9.2	23.1	4,539
	-20	100	2.5	.04	.15	157	15.1	1.9	17.0	2,681
		300	2.5	.04	.15	157	15.1	5.7	20.8	3,275
		500	2.5	.04	.15	157	15.1	9.4	24.5	3,870
75	-10	100	6.0	.09	.35	420	27.9	1.7	29.6	12,450
		300	6.5	.09	.37	457	25.5	4.9	30.4	13,897
		500	6.5	.09	.37	457	25.5	8.1	33.6	15,388
	-15	100	4.5	.07	.27	309	27.9	1.7	29.6	9,171
		300	4.5	.07	.27	309	27.9	5.2	33.1	10,254
		500	5.0	.07	.30	347	24.2	8.6	32.8	11,377
	-20	100	3.5	.05	.21	234	30.3	1.8	32.1	7,520
		300	3.5	.05	.21	234	30.3	5.4	35.7	8,370
		500	4.0	.06	.24	272	25.4	8.9	34.3	9,330
100	-10	100	8.5	.11	.46	601	40.8	1.5	42.3	25,455
		300	9.0	.12	.48	636	38.4	4.5	42.9	27,314
		500	9.0	.12	.48	636	38.4	7.5	45.9	29,224
	-15	100	6.0	.09	.35	420	41.9	1.7	43.5	18,326
		300	6.5	.09	.37	457	38.2	4.9	43.1	19,727
		500	6.5	.09	.37	457	38.2	8.1	46.4	21,218
	-20	100	5.0	.07	.30	347	40.6	1.7	42.3	14,683
		300	5.0	.07	.30	347	40.6	5.2	45.7	15,876
		500	5.0	.07	.30	347	40.6	8.6	49.2	17,068

VKILL = value of a kill
QP = quitting point
SR = success rate
HR = harvest rate
DAF = days afield
TB = total benefits
TBE = total experience benefits
TBK = total kill benefits

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values for C_o, C_1, and VKILL. Performance measures include the quitting point (QP), success rate (SR = KILL/NH), harvest rate (HR = KILL/NDVUL), days afield (DAF), the total hunter benefits measure from Section 5.4 (TB), and total benefits from the experience (TBE), and the kill (TBK) per day afield.

The roles of C_o, C_1, and VKILL in the valuation function are made more apparent by these experiments. C_o sets the basic level for total hunter benefits generated. Notice that for a fixed value of C_o total benefits do not fluctuate too widely with changes in C_1 and VKILL. Higher values for C_o result in successively greater hunter benefits.

C_1 is more a determinant of how long the hunter remains afield as it indicates how steeply the marginal benefit curve V_u drops off with increased consumption. The larger C_1, the fewer days spent hunting and the fewer benefits generated. Success rates and harvest rates also decrease with hunting effort and thus are inversely related to C_1.

Larger values of VKILL naturally result in greater hunter benefits as each deer killed becomes worth more; however, in addition to increasing benefits, it also leads to more days afield, especially for the "gambling hunter" such as the MEAT hunter mentioned earlier. These hunters have high values for VKILL relative to C_o. The value of VKILL has a significant effect on the relative per day benefits from the kill (TBK/DAF) and the experience (TBE/DAF).

More specifically, Table 6.2 shows the effect of a doubling of each of the valuation parameters on selected performance measures.

TB
Doubling C_o:
+(300-650%)
Doubling C_1:
-(33-41%)
Doubling VKILL
+(5-10%)

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Table 6.2 Summary of Sensitivity Analysis

TB	DAF	TB/DAF	TBE/DAF	TBK/DAF
Doubling C_o:				
+(300-650%)	+(120-160%)	+(100-175%)	+(170-275%)	-(12-16%)
Doubling C_1:				
-(33-41%)	-(33-50%)	+(0-30%)	±(0-15%)	+(0-15%)
Doubling VKILL:				
+(5-10%)	+(0-10%)[a]	-(1-11%)	-(0-10%)[a]	+(90-110%)

[a]Over the range of values used for C_o, and C_1, only $C_o = 50$, $C_1 = -10$ exhibits sensitivities in the high range. Sensitivities of VKILL would be greater if probabilities of a kill per day were greater (here $p = .02$ is used).

The range of sensitivities reported in Table 6.2 is a result of varying two parameters simultaneously. In examining the effect of a doubling of each parameter, the other two parameters are varied over the ranges reported in Table 6.1.

Table 6.2 reinforces the previous analysis. VKILL predominantly influences kill benefits, although it can significantly affect TB, DAF, and other performance measures if probabilities of a kill are high. This is evident in the model where the term $p \times \text{VKILL}$ appears in the decision on when to quit hunting. This term is the expected kill benefit and becomes significant if the product is comparable in size to experience benefits measured by $C_o + C_1 \times n$. This can occur if either p or VKILL is sufficiently large.

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C_o has its major impact on total benefits generated for hunters (TB) with a 100% increase in C_o resulting in a 100-175% increase in per day benefits. Days afield also increase by a similar amount yielding increases in total benefits as large as 650%. Larger values of hunting experiences represented by C_o result in both higher per day values as well as increasing the number of days hunted, leading to five- and sixfold increases in total benefits to hunters.

Doubling C_1 leads to 33-41% decreases in benefits (TB), but this is primarily due to the resulting decrease in days spent hunting which drop off 33-50%.

This sensitivity analysis is at a very coarse level. Incomplete knowledge of hunter valuation implies that a wide range of parameter values must be considered. This initial examination of the sensitivity of the valuation model to changes in the parameters gives a better understanding of the operating characteristics of the model and the significance of each parameter. Once one or more of the parameters are pinned down, the sensitivity of remaining parameters may be examined at a finer level.

For the purpose of this study, subsequent analysis will assume valuation parameters for one or more groups of hunters so that other characteristics of the model may be examined.

6.1.2 Hunter and Deer Stocking Decisions

Having identified the importance of the three valuation parameters in measuring benefits to hunters, the analysis now turns to the problems

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to the problems of managing hunter and deer populations to maximize returns based on the performance measures.

As noted in the general hunting model, different kinds of hunters most likely will have different valuation functions putting more or less value on the kill as opposed to the experience. These differences are reflected in the three parameters examined above, and show up in the behavioral characteristics of the resulting alternative model formulations. These will be explored here. There may be great danger in managing areas based on some "average valuation function." Policies designed to satisfy the average hunter may wind up pleasing no one.

As discussed in the general hunting model, the ideal situation is to treat each hunter separately, but this is quite impossible. The compromise is to segment the hunter population into meaningful groups, just as commercial enterprises use market segmentation to best satisfy their customers. In managing to maximize benefits to hunters, the valuation function provides a reasonable criterion for segmenting hunters. Then performance of the system in satisfying each group may be measured, compared, and added up to determine overall performance. In this way, management can tell who is benefitting most and what tradeoffs are being made between different user groups.

Such a framework begins to get to the heart of multiple use considerations. Just as hunters are considered a distinct use from wildlife photographers, MEAT hunters may be considered different users than EXPERIENCE hunters, and should be, if the groups imply different kinds of syster

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kinds of system behavior. Thus, although in identifying the DFH system, this study has omitted directly conflicting uses such as timber harvesting and agriculture, this does not preclude the illustration of such multiple use conflicts. This can be done within the hunter system.

The first hunter stocking decision to be examined, namely, which kinds of hunters to stock, can be thought of in terms of multiple use decision-making. For the purposes of this study, the two groups of hunters hypothesized earlier and termed MEAT and EXPERIENCE hunters will be examined in this context. MEAT hunters are assumed to be characterized by a valuation function with parameters $C_o = 50$, $C_1 = -10$, and VKILL = 500. EXPERIENCE hunters are assumed to have parameter values of $C_o = 100$, $C_1 = -20$, and VKILL = 100. The probability of success is assumed to be the same for each group for a given deer herd density.

Deer Stocking

Table 6.3 shows the sensitivity of MEAT and EXPERIENCE hunters to different levels of deer stocking. Eighty hunters of each type were tested in turn on the hunting model and performance measures generated for a single hunting season.

The most significant difference between the two groups of hunters is the effect of the deer densities on total benefits. MEAT hunters are highly sensitive to deer with benefits increasing from \$5,880 with 20 deer to \$16,954 with 100 deer; whereas EXPERIENCE hunter benefits remain near \$15,000 with little change with higher deer densities. Note that if managing to maximize total benefits, one would

ND	QP
20	4.5
40	5.0
60	5.5
80	6.5
100	7.0
20	5.0
40	5.0
60	5.0
80	5.0
100	5.0

QP = quittin
SR = success
HR = harvest
DAF = days af

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Table 6.3 Deer Stocking (with 80 Hunters)

ND	QP	SR	HR	DAF	TBE/DAF ($/day)	TBK/DAF ($/day)	TB/DAF ($/day)	TB ($)
				MEAT Hunters				
20	4.5	.07	.27	310	10.2	8.7	19.0	5,880
40	5.0	.14	.29	334	8.1	17.3	25.4	8,488
60	5.5	.23	.30	354	6.1	25.6	31.7	11,243
80	6.5	.33	.33	394	2.0	33.5	35.5	14,073
100	7.0	.42	.34	402	0.5	41.7	42.2	16,954
				EXPERIENCE Hunters				
20	5.0	.07	.30	347	40.6	1.7	42.3	14,683
40	5.0	.14	.29	334	41.2	3.5	44.6	14,939
60	5.0	.21	.28	322	41.8	5.2	47.0	15,167
80	5.0	.27	.27	311	42.4	7.0	49.4	15,370
100	5.0	.33	.26	300	43.0	8.8	51.8	15,549

QP = quitting point
SR = success rate
HR = harvest rate
DAF = days afield
TBK = total benefits from kill
TB = total benefits
ND = number of deer (huntable)
TBE = total benefits from experience

maximize revenues by managing for MEAT hunters only if deer densities exceed 80.

One can also note the distinction in distribution of net benefits to hunters. All EXPERIENCE hunters receive benefits which are relatively the same; i.e., there is little difference between successful and unsuccessful hunters as a result of the low value placed on the kill relative to the experience.

MEAT hunters, on the other hand, reflect the consequences of the greater "gambling" nature of their hunt. At deer densities of over

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100, per-day experience benefits (TBE/DAF) actually drop to zero and below. This means that unsuccessful hunters receive no net benefits at all from their six days of hunting, and may actually experience negative net returns due to costs of participating. The revenues accrue only to the successful hunters who reap the benefits of the kill and are able to quit the hunt before a full six days of hunting.

Also note the contribution of MEAT hunters in controlling the deer population. As deer densities increase for the MEAT group, harvest rates also rise. Harvest rates for the EXPERIENCE group actually decline with increasing deer densities due to the fact that EXPERIENCE hunters are not influenced to remain afield longer simply because of higher probabilities of a kill. While the assumption that a fixed group of 80 hunters does all of the hunting on the area may be unrealistic, running the model with this assumption shows how hunters who pursue deer primarily for the kill help to control overpopulation of deer by seeking out those areas with high herd densities and hunting more often there.

Although both groups benefit from increased deer populations, when the costs of maintaining higher deer density are considered the two might imply different kinds of management. Extensive habitat management would most likely not be justified for the EXPERIENCE group if TB were used as the performance measure and management costs subtracted from these benefits, as little additional revenue is generated. Of course, it is assumed here that the number of hunters using the area is fixed. The next section examines the effect of increasing hunter densities for the two groups of hunters.

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40	4.5
80	4.5
120	4.5
160	4.5
40	5.0
80	5.0
120	5.0
160	5.0

QP = quittin
SR = success
HR = harvest
DAF = days af

Hunter Stocking

Table 6.4 examines the hunter stocking question for MEAT and EXPERIENCE hunters on an area with 20 deer. In the absence of a congestion factor, the depletion of the herd is the only limiting factor in the generation of benefits. Over a single season depletion is not significant enough to result in negative returns to total benefits. Depletion can, however, significantly affect benefits generated over a number of hunting seasons. This will be examined shortly, once the ecosystem model is added to the hunting model.

Table 6.4 Hunter Stocking (with 20 Deer)

NH	QP	SR	HR	DAF	TBE/DAF ($/day)	TBK/DAF ($/day)	TB/DAF ($/day)	TB ($)
				MEAT Hunters				
40	4.5	.07	.14	155	10.2	9.3	19.6	3,032
80	4.5	.07	.27	309	10.2	8.7	19.0	5,880
120	4.5	.06	.34	408	12.7	8.4	21.1	8,617
160	4.5	.05	.43	545	12.7	7.9	20.6	11,240
				EXPERIENCE Hunters				
40	5.0	.08	.16	173	40.6	1.9	42.5	7,360
80	5.0	.07	.30	347	40.6	1.7	42.3	14,683
120	5.0	.07	.42	521	40.5	1.6	42.1	21.975
160	5.0	.06	.52	696	40.5	1.5	42.0	29,240

QP = quitting point
SR = success rate
HR = harvest rate
DAF = days afield

TBK = total benefits from kill
TB = total benefits
NH = number of hunters
TBE = total benefits from experience

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In both the MEAT and EXPERIENCE hunter simulation runs, increasing the number of hunters primarily affects the total days afield (DAF) and hence harvest rates (HR) and total benefits (TB). The small decreases in success rates (SR) and in benefits from kills (TBK/DAF) reflect the depletion effect over a single season, as the deer population, probability of a kill, and resulting number of successes per unit effort decrease as the season progresses. The more hunters that begin on opening day, the faster and greater the decline in successes.

One obvious and useful relationship from Table 6.4 is the one between the number of hunters and harvest rates. In proceeding to integrate the ecosystem model with the hunting model in the next section, the only significant impact of hunters on the ecosystem is their contribution to the deer population in the form of the annual hunting season harvest. Thus harvest rates (HR) provide an important measure of the performance of the hunting model in terms of its effect on the ecosystem model.

The differences between MEAT and EXPERIENCE hunters reflected in the relationships of hunting effort and deer densities to harvest rates for the two groups are significant. In Table 6.3 harvest rates of MEAT hunters increase while those of EXPERIENCE hunters decrease with increasing deer densities. In Table 6.4 harvest rates from EXPERIENCE hunters increase more rapidly than those of MEAT hunters with increasing numbers of hunters. This is due to the fact that EXPERIENCE hunters spend more days afield at the low deer density

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examined there (20 deer) and do not cut back hunting occasions in the light of low success rates. At higher deer densities, MEAT hunters would spend more time in the field as is shown in Table 6.3.

This demonstrates the interrelationship between deer and hunter stocking decisions, including both numbers and kinds of both deer and hunters. Tables 6.3 and 6.4 illustrate the influence of the kind of hunter on the performance of the system. So far, deer have been treated simply as numbers, with the number of deer denoting the number susceptible to the hunt. In Section 6.3 it will be seen how important the makeup of this deer population is, in terms of age and sex.

Interrelationships Between Hunter and Deer Stocking

Returning to numbers of deer (ND) and hunters (NH), the interrelationship of these two stocking decisions in determining CC can be highlighted by examining two of the system performance measures, namely success rate (SR) and harvest rate (HR). The former looks at the kill in terms of hunters and the latter in terms of deer. Simply examining the definition of these two performance measures and their treatment within the model is sufficient to illustrate the linkages.

Success rate is defined by SR = KILL/NH, but is largely determined by the number of deer present. Similarly, harvest rate is defined by HR = KILL/ND, but is largely determined by the number of hunters. This apparent contradiction can be cleared up by examining the linear model for hunting.

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Kills per day of hunting are obtained by multiplying the probability of a kill times the number of hunters (per day kill = $(B_1 \times ND) \times NH$). If depletion effects are ignored and successful hunters remain afield, kills for the season are obtained by multiplying the per day kill times the number of days spent hunting, which is simply one less than the quitting point $(QP - 1)$. Thus $KILL = (B_1 \times ND) \times NH \times (QP - 1)$.

Substituting this in the definitions of SR and HR yields the following:

$$SR = KILL/NH = (B_1 \times ND) \times NH \times (QP - 1)/NH = B_1 \times ND \times (QP - 1)$$

$$HR = KILL/ND = (B_1 \times ND) \times NH \times (QP - 1)/ND = B_1 \times NH \times (QP - 1)$$

Thus the model implies that success rates are linearly related to deer densities and harvest rates are similarly related to hunting effort, if in-season kills and successful hunters are assumed to be replaced.

Success rate has been the traditional measure of quality in hunting, whereas harvest rate, being closely related to hunting effort, is more a measure of the quantity of hunting. (DAF is of course a better measure of quantity of hunting effort.) A goal of maintaining a sustained yield in terms of both quality and quantity of hunting from a forest resource requires consideration of both of these performance measures. One cannot manage just to maintain high success rates or high harvest rates over the long term without consideration of the other. Combining the two definitions to yield the equation, provides the

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$$\frac{SR}{HR} = \frac{ND}{NH}$$

provides the most concise statement of the interrelationship of success rates, harvest rates, and deer and hunter populations.

6.1.3. Performance Measures

Before proceeding into the ecosystem and combined simulations, the other performance measures appearing in Tables 6.1 to 6.4 will be discussed. The total benefits (TB) performance measure is the one derived in Section 5.4. It is an attempt to combine quality and quantity measures into a single performance measure. It includes both kill benefits (related to success rates) and experience benefits (closely related to hunting effort or DAF) net of costs incurred by hunters. It is only a suggested performance measure and needs refinement.

In addition to success rate (SR), harvest rate (HR), and total hunter benefits (TB), Tables 6.1 to 6.4 also report a measure of the quantity of hunting effort (DAF), and three "quality measures." The quality measures are TB/DAF, TBE/DAF, and TBK/DAF. These are per day benefit measures and provide a measure distinct from corresponding TB, TBE, and TBK. The total benefit measures may increase simply by providing more days of hunting. The per day benefit measures begin to look at quality consideration, although in the absence of a congestion component they mostly measure depletion effects. This can be seen in Table 6.4 where kill benefits per day afield decrease even though total benefits are increasing with additional hunters. The additional days of hunting are

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It must be remembered that the analysis so far has been limited to a single hunting season. As long-term effects of hunting and habitat management are introduced in Section 6.2, these performance measures will have to be refined to take account of long-term objectives.

6.1.4 Additional Notes on Data Gathering and Calibration

The simulation experiments give additional direction to data gathering efforts beyond the contribution of modeling itself. The models specify precise requirements for the kinds of data needed in calibration. Simulation experiments such as the sensitivity analyses examined above give better indications of the value and precision requirements of such data.

The preceding analysis of valuation parameters helps to pinpoint the relative importance of each parameter in terms of its contribution to the measures of system performance. This gives the researcher an idea of the effect of errors in input data on outputs of the model.

In addition to the ability of simulation models to perform sensitivity analyses, they also can facilitate indirect methods of calibrating model components for which direct data gathering is difficult or costly. The calibration of the valuation functions is a good example.

Direct survey techniques to determine hunter valuation of experiences yield inconsistent and questionable results (Fischer, 1975).

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Simulation provides an opportunity to set parameters by adjusting them until outputs of the model correspond with more observable empirical data.[2] Table 6.1 permits the examination of the effects of different valuation parameter settings on success rate, harvest rate, days afield, and quitting points. Some parameter settings yield reasonable responses while others do not.

Such iterative parameter setting techniques should be supplemented with sufficient data gathering to achieve the desired degree of confidence in the model. The traditional survey methods of determining values for recreation can be far more useful when used in conjunction with a model, and especially when used with a simulation model.

A simulation model both pinpoints the kind of data needed and provides a means of checking the consistency of responses. Surveys could gather data on valuation as well as actual behavior. Questions could be designed to calibrate the diminishing returns model for valuing hunting experiences, and then by simulating with these valuation functions the model could be tested to see if behavioral variables such as days afield, success rate, and harvest rate are accurately predicted. Lack of consistency would indicate either that the gambling model is lacking or that what hunters say is not what they do. Consistent responses would give more credibility to both the model and the values generated for hunting experiences.

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Detailed discussions of validation of the model will not be given here. In general, a series of experiments are run on the model to test its ability to predict. For recreation systems, appropriate real world data for detailed validation experiments does not exist. Smith and Krutilla (1975) note this to be the case with the wilderness trip simulator. They have used Turing methods to validate their model. This involves interaction between experts on the behavior of the real world system with simulation experiments to test the "reasonableness" of the model response. More rigorous experiments can be devised in which managers attempt to distinguish between outputs of the model and real-world data.

In general, both the kind and degree of validation required of the model will depend on the purposes for which it will be used. No model can be truly validated as one can never be sure of the behavior of the real-world system due to measurement and perception errors. Naylor (1969) and Naylor and Finger (1967) discuss validation of simulation models in more detail.

6.2 Experiments on the Ecosystem and Combined Models

The previous section examined the hunter subsystem model by itself. Similar experiments could be carried out on the ecosystem model. These will be omitted here as the analysis proceeds directly into the dynamic relationships between the ecological and hunter subsystems and explores the significance of these interactions in CC determinations.

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The simulation experiments on the combined hunter-ecosystem model are designed first to illustrate the behavioral characteristics of the model and second to explore the contribution of such simulation experiments to the understanding and research of CC in the DFH case. In view of the neglect of dynamics and the interrelatedness of management stocking decisions in previous treatments of RCC, the illustration of these characteristics will be a principal thrust of these simulation experiments. Indeed, in the DFH system dynamics are difficult to ignore. While dynamic considerations may be less important in other kinds of CC studies, they are present in all systems.

6.2.1 The Ecosystem Model

The behavior of the ecosystem model can be seen by tracing out the time paths of selected system performance variables. This is carried out in the following sequence of figures where alternative stocking levels of deer and hunters, and alternative harvesting and clearcutting controls are examined on a simulated forest system over a 50-year time period.

All simulation runs begin with the same initial states and parameters (see Appendix B for the ecosystem parameters), so that comparisons may be made. Each experiment begins with a forest that has been harvested, clearcut, or burned. An initial planting of saplings and a seed basis for shrubs and grasses provides the basis for plant growth.

All variables are scaled to fit onto the same graph and the same scaling is used throughout all of the runs. Deer (D) represent

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actual counts. Winter food supplies (W) are a factor of 10 less than summer food values (S). Tree biomass (A) represents the stage of maturity of the forest. The computer graphs of Figures 6.1 to 6.6 suffice to illustrate the qualitative kinds of relationships being examined here. As the model is not calibrated to represent any specific forest area, drawing quantitative conclusions about a real-world system should be avoided.

Figure 6.1 examines the behavior of the vegetative component of the system in the absence of deer. From the initial planting, tree biomass (A) exhibits a logistic pattern of growth reaching a stable level in 20 years. Summer and winter food supplies both increase rapidly, reaching a peak within six years and then decline as the forest matures to eventually reach stable levels in the mature forest.

Introduction of Deer

Figure 6.2 shows the behavior of the same system with an initial stocking of 20 deer (two of each age and sex class) in the absence of a hunter harvest. Deer populations respond to the available food supply, with peak deer populations lagging about six years behind the peak food supply. The introduction of deer causes the food supplies to decline more rapidly after the six-year peak. The heavy feeding pressure during peak deer population years reduces both the summer and winter food supplies. The marked reduction in winter browse results in the curtailment of the deer population increase, as birth rates fall off and natural mortality brings the deer population back into equilibrium with the food supply.

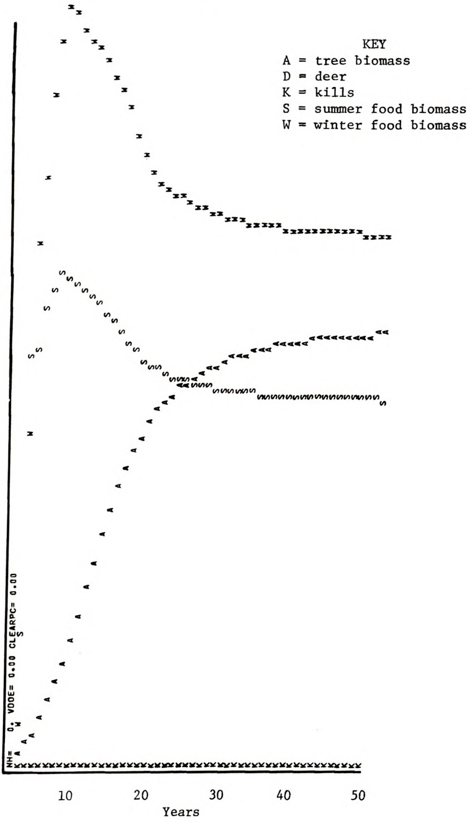

Figure 6.1 -- Plant Growth in the Absence of Deer

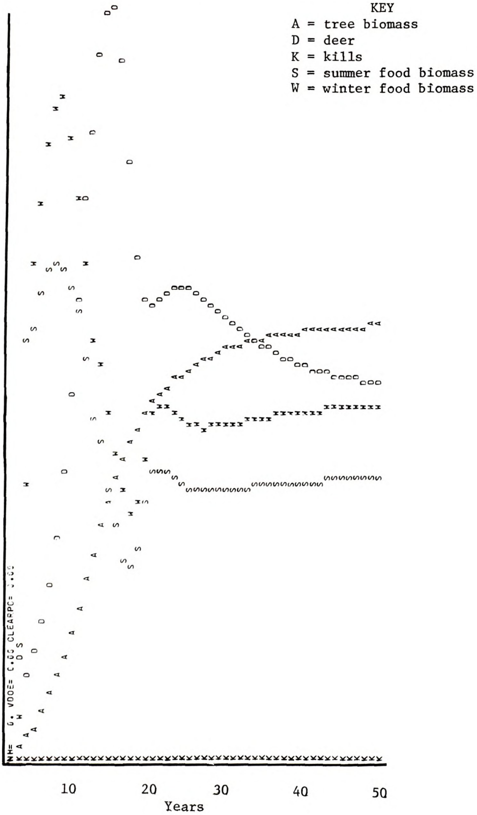

Figure 6.2 -- Introduction of Deer - No Hunt

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After 20 years the deer population levels off to about 50 deer, less than half of the peak deer population. Food supplies recover somewhat once the deer herd is reduced and the system is near equilibrium at the 20-year mark. Notice that for the system of Figure 6.2 natural controls are sufficient to bring deer and forest in balance.

6.2.2 The Combined Hunter-Ecosystem Model

Although natural ecological feedback mechanisms bring deer populations to near 50 in the mature forest of our hypothetical site, no benefits are generated for hunters in such a system. (There may, however, be benefits to non-consumptive users of wildlife.) Figures 6.1 and 6.2 represent unmanaged systems.

Artificial controls imposed by management on the system may result in higher or lower deer populations and also larger or smaller net benefits for man. In particular, any extra benefits reaped from management of the site must be weighed against the cost of such management. The cost side of the picture will not be explicitly treated here, as the concentration is on benefits derived by hunters from the site.

In the following sequence of experiments varying numbers of hunters will be input to the system each fall to carry out the harvest. The hunting model described in Section 5.6 will be used to simulate deer kills and hunter benefits. For demonstration purposes a single uniform class of hunters will be used. MEAT hunters with valuation parameters $C_o = 50$, $C_1 = -10$, and VKILL = 500 have been selected. The effe

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effect of using different valuation functions was explored in Tables 6.1-6.3 of the previous section, where it was seen that the primary effect on the ecosystem is in terms of the numbers of deer harvested.

Three kinds of controls are illustrated in Figures 6.3-6.6: (1) control of the numbers of hunters taking part in the harvest, (2) control of which deer are vulnerable to the hunt, and (3) clear-cutting controls. These were described in Section 5.1.

Figure 6.3 shows the behavior of the system with an annual bucks-only hunt and 160 hunters. The deer population levels do not differ significantly from the no-harvest run of Figure 6.2, except that the peak is delayed a couple of years, the drop off after the peak is less sharp, and equilibrium deer populations are slightly higher with the harvest. The age/sex makeup of the deer population is, however, quite different as the buck harvests result in deer herds with high percentages of does and mostly younger bucks. Benefits are enjoyed by hunters from their experiences and harvests of up to 10 deer annually.

Figure 6.4 illustrates the behavior of the system with a 50% doe vulnerability and only 60 hunters per year. The doe harvest lowers the peak deer population and yields a slow continuous decline in the numbers of deer following the peak. It appears here that the harvest of does is too great to sustain the deer herd and such a scheme could result in the virtual extinction of the deer herd.

Figure 6.5 illustrates the role of clearcutting in sustaining deer populations by increasing food supplies. With the same 60 hunters

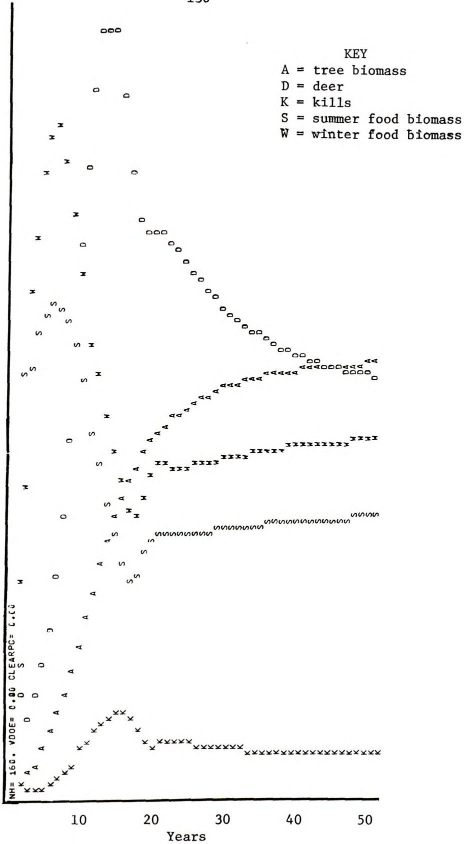

Figure 6.3 -- Bucks-only Hunt

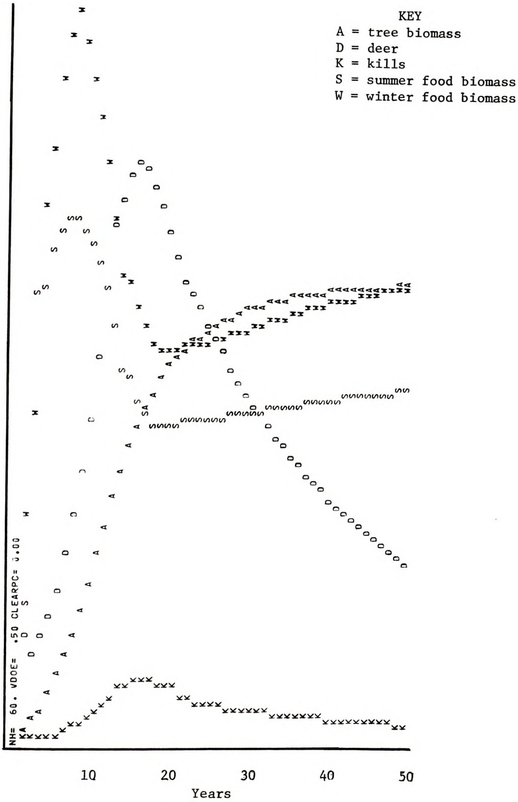

Figure 6.4 -- Partial Doe Hunt

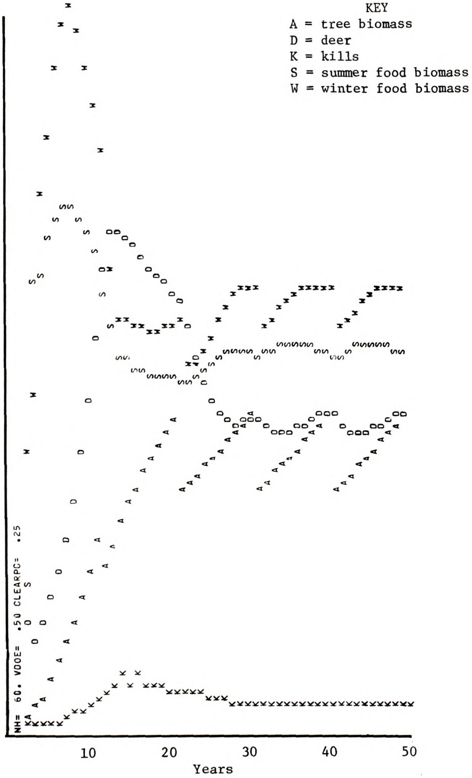

Figure 6.5 -- Partial Doe Hunt with 25% Clearcut

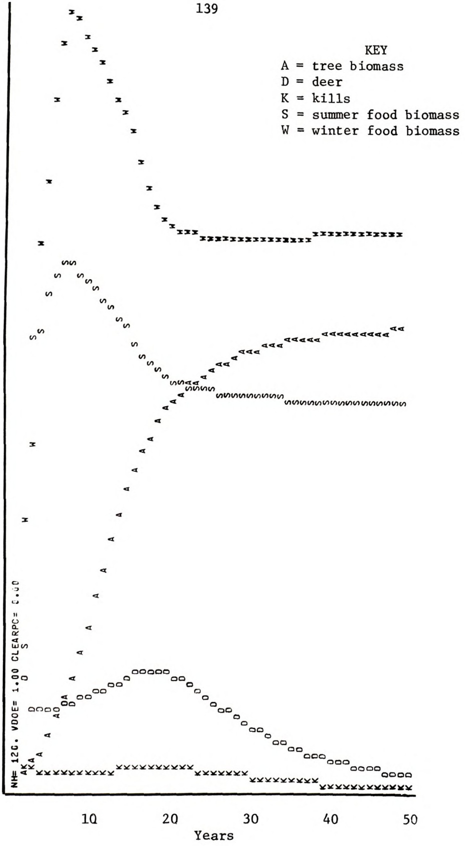

Figure 6.6 -- Full Doe Harvest

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and a 50% doe vulnerability as in Figure 6.4, a 25% clearcut is introduced every 10 years. Once the forest has matured, the clearcuts provide new growth and food for deer. This brings deer populations to an equilibrium level of 39. Note that although the periodic clearcuts yield oscillations in food supplies, deer populations remain quite stable between years 20 and 50.

Figure 6.6 shows the results of allowing 120 hunters each year with a full doe harvest. The deer population never really gets started and becomes extinct with only a few kills early in the simulation.

RCC Revisited

These six experiments should serve to indicate the variety of simulations which might be carried out on the model of the DFH system. The suggested framework for exploring CC determinations (for both deer and hunters) is to carry out similar experiments for a variety of different hunter and deer stocking levels as well as a variety of potential management schemes.[3]

Figures 6.1-6.6 only begin to touch the surface of the alternatives which might be explored. All of the above experiments are static management schemes and deal with fixed stocking levels of hunters. More complex schemes might explore changing hunter stocking levels from year to year, varying clearcutting patterns, or periodically stocking deer artificially.

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[3]The reader may wish to reread Section 3.3 to review the proposed general framework for RCC determination in the light of the DFH example.

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It should be reemphasized that decisions on use levels (CC) and management are interdependent and must be tied to management objectives via system performance measures. Each CC of the site should be associated with a set of objectives and management strategies. CCs of both deer and hunters will change with clearcutting and doe harvesting choices and with management objectives. As the system and objectives will change with time, so will CCs.

By introducing the dynamic character of the DFH system, the CC decision has become much more complex. The deer population dynamics only begin to illustrate the complexities. By treating hunter inputs as exogenous, hunter population dynamics have not been considered. Just as an initial input of 20 deer may lead to 60 or 70 in 10 years, an initial input of 100 hunters may result in pressure from 500 to 600 in 10 years of time. On the other hand, just as the deer herd may become extinct from overhunting or inadequate food supplies, so might the number of hunters if success rates are low, or other opportunities compete for their time and money. This begins to get to interactions included in the management-management group. By permitting or restricting certain levels or kinds of hunting in the present, management will be constrained in the kinds of management that it can carry out or will be forced to carry out in the future.

Including the long-term effects of management and use and the complexities of a dynamic user and environmental system make decisions dealing with use and management policy extremely complex. The next section will explore the use of simulation to organize the information needed to make these decisions.

6.3 Potential of Simulation for RCC Policy Analysis

In this section it will be assumed that the model and simulation runs of Figures 6.1-6.6 represent an actual real-world system. This will permit an exploration of the potential of such a model for making management policy decisions related to CC. One of the shortcomings of simulation noted earlier is the need for replications as the model does not generate "optimal solutions." The DFH model is capable of rapidly generating thousands of runs like those of Figures 6.1-6.6 for the thousands of possible combinations of management and use. To be of use to policy analysis some means of organizing this information in a meaningful way is required.

Table 6.5 depicts one kind of summary output that might be of use to managers and policy analysts. The relative performance of the DFH system under alternative management and use schemes for a 50-year period is summarized using selected performance measures. Selected combinations of hunter stocking, doe vulnerabilities, and clearcutting are examined.

A number of distinct performance measures are reported to allow policy analysts to examine tradeoffs in meeting different objectives or in satisfying different interest groups. Ideally one would include measures of performance for each distinct objective and user group. The measures reported in Table 6.5 are only meant to be illustrative. The refinement of these performance measures and corresponding objectives will be discussed shortly.

Tab

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Table 6.5 Performance of Alternative Management Systems: Fixed Control

CUT	NHO	VDOE	ND	NDVUL	KILL	DAF	SR	HR	TB	NH	ND50	B50
0.00	40.	0.00	70.4	21.3	3.2	153.2	.08	.14	3.2	40.0	54.	15.
0.00	60.	0.00	71.9	2[illegible].3	4.3	227.0	.07	.21	4.6	60.0	54.	13.
0.00	80.	0.00	72.6	19.3	5.3	30[illegible].3	.07	.27	5.9	80.0	54.	11.
0.00	100.	0.00	73.3	18.4	6.1	376.1	.06	.33	7.1	100.0	54.	10.
0.00	120.	0.00	73.8	17.5	6.8	452.0	.06	.38	8.3	120.0	54.	9.
0.00	140.	0.00	74.2	16.8	7.4	525.3	.05	.43	9.4	140.0	54.	8.
*0.00	160.	0.00	74.6	15.2	7.9	601.0	.05	.48	1[illegible].4	160.0	54.	7.
.25	40.	0.00	80.0	24.3	3.5	151.1	.09	.14	3.4	40.0	74.	20.
.25	60.	0.00	81.0	22.9	4.8	225.1	.08	.21	4.8	60.0	74.	17.
.25	80.	0.00	81.8	21.7	5.9	299.3	.07	.27	6.2	80.0	74.	15.
.25	100.	0.00	82.5	20.6	6.8	374.8	.07	.33	7.5	100.0	74.	13.
.25	120.	0.00	83.1	19.7	7.6	450.5	.06	.38	8.7	120.0	74.	12.
.25	140.	0.00	83.5	18.9	8.3	523.7	.06	.43	9.8	140.0	74.	10.
.25	160.	0.00	83.9	18.2	8.9	599.3	.06	.48	10.9	160.0	74.	9.
.50	40.	0.00	77.0	23.4	3.4	149.9	.08	.14	3.3	40.0	69.	18.
.50	60.	0.00	77.6	21.9	4.6	225.5	.08	.21	4.7	60.0	70.	16.
.50	80.	0.00	78.1	20.7	5.7	299.7	.07	.27	6.1	80.0	70.	14.
.50	100.	0.00	78.5	19.6	6.5	375.4	.07	.33	7.3	100.0	70.	12.
.50	120.	0.00	78.8	18.7	7.2	451.2	.06	.38	8.5	120.0	70.	11.
.50	140.	0.00	78.9	17.9	7.8	524.5	.06	.43	9.6	140.0	70.	10.
.50	160.	0.00	79.1	17.1	8.3	600.2	.05	.48	10.7	160.0	70.	9.
0.00	40.	.50	57.3	28.4	4.4	159.9	.11	.15	3.7	40.0	34.	10.
*0.00	60.	.50	49.3	23.7	5.2	234.4	.09	.21	4.9	60.0	22.	6.
0.00	80.	.50	42.5	20.0	5.3	289.3	.07	.26	[illegible].0	80.0	19.	5.
0.00	100.	.50	36.3	16.7	5.2	344.1	.05	.30	6.8	100.0	17.	4.
0.00	120.	.50	31.4	14.2	5.1	400.6	.04	.35	7.7	120.0	15.	3.
0.00	140.	.50	27.9	12.4	4.9	455.0	.04	.39	8.5	140.0	13.	3.
0.00	160.	.50	25.3	11.[illegible]	4.8	508.6	.03	.42	9.4	160.0	10.	2.
.25	40.	.50	55.5	27.4	4.2	159.5	.11	.15	3.6	40.0	42.	12.
* .25	60.	.50	49.3	23.7	5.0	228.2	.08	.21	4.9	60.0	39.	11.
.25	80.	.50	45.2	21.1	5.7	301.2	.07	.27	6.1	80.0	36.	9.
.25	100.	.50	41.6	18.9	6.2	375.9	.06	.33	7.2	100.0	33.	7.
.25	120.	.50	38.4	17.0	6.5	450.1	.05	.38	8.1	120.0	29.	6.
.25	140.	.50	34.6	15.[illegible]	6.5	524.[illegible]	.05	.43	9.0	140.0	24.	4.
.25	160.	.50	32.3	13.8	6.4	556.7	.04	.45	9.9	160.0	24.	4.
.50	40.	.50	54.5	26.9	4.0	153.5	.10	.14	3.5	40.0	54.	16.
.50	60.	.50	52.3	25.[illegible]	5.3	225.6	.09	.21	5.[illegible]	60.0	51.	14.
.50	80.	.50	50.3	23.3	6.4	300.2	.08	.27	6.4	80.0	48.	12.
.50	100.	.50	47.5	21.5	7.1	374.4	.07	.33	7.6	100.0	44.	10.
.50	120.	.50	43.8	19.3	7.4	448.5	.06	.38	8.6	120.0	40.	8.
.50	140.	.50	39.2	16.9	7.4	522.6	.05	.43	9.4	140.0	35.	6.
.50	160.	.50	33.7	14.3	6.9	593.4	.04	.47	10.0	160.0	29.	5.
0.00	40.	1.00	36.7	24.3	3.8	160.4	.09	.15	3.4	40.0	16.	5.
0.00	60.	1.00	26.9	17.3	3.5	213.1	.06	.20	4.2	60.0	13.	4.
0.00	80.	1.00	20.0	12.6	3.2	269.1	.04	.24	5.0	80.0	8.	2.
0.00	100.	1.00	14.5	9.0	2.6	316.7	.03	.28	5.7	100.0	4.	1.
*0.00	120.	1.00	10.7	6.6	2.1	357.7	.02	.32	6.4	120.0	2.	0.
0.00	140.	1.00	6.3	3.9	1.4	418.5	.01	.36	7.0	140.0	0.	0.
0.00	160.	1.00	3.9	2.4	1.0	478.9	.01	.41	7.7	160.0	0.	0.
.25	40.	1.00	42.1	27.7	4.1	156.9	.10	.15	3.6	40.0	35.	11.
.25	60.	1.00	34.4	21.9	4.6	227.9	.08	.21	4.7	60.0	26.	8.
.25	80.	1.00	23.5	14.6	4.0	301.0	.05	.27	5.2	80.0	15.	4.
.25	100.	1.00	18.8	11.6	3.3	315.9	.03	.28	6.0	100.0	14.	4.
.25	120.	1.00	12.9	7.9	2.5	357.3	.02	.32	6.6	120.0	6.	2.
.25	140.	1.00	7.0	4.2	1.5	418.3	.01	.36	7.1	140.0	1.	0.
.25	160.	1.00	4.1	2.5	1.0	478.9	.01	.41	7.7	160.0	0.	0.
.50	40.	1.00	46.9	30.6	4.9	168.2	.12	.16	3.8	40.0	44.	14.
.50	60.	1.00	39.2	24.8	5.2	226.9	.09	.21	5.0	60.0	37.	11.
.50	80.	1.00	24.1	14.8	4.1	304.0	.05	.27	5.3	80.0	19.	5.
.50	100.	1.00	18.4	11.3	3.2	319.9	.03	.29	6.0	100.0	15.	4.
.50	120.	1.00	11.9	7.3	2.3	357.5	.02	.32	6.5	120.0	6.	2.
.50	140.	1.00	6.2	3.8	1.4	418.5	.01	.36	7.0	140.0	1.	0.
.50	160.	1.00	3.8	2.3	.9	478.9	.01	.41	7.7	160.0	0.	0.

CUT = percent clearcut
NHO = desired number of hunters
VDOE = doe vulnerability
NDVUL = number of huntable deer
KILL = deer harvest
NH = actual number of hunters
ND50 = terminal deer population
B50 = terminal buck population

Table 6.5 includes measures of the state of the deer population as well as the benefits derived by hunters. Measures of the state of the forest might also be included depending on the purposes of the policy analysis. Total hunter benefits (TB) are the 50-year sums (in thousands of dollars) of the benefits received by hunters each year. There is no discounting here. The other performance measures in Table 6.5 are yearly averages over the 50-year run. These include the average number of deer (ND), the average number vulnerable to the hunt (NDVUL), average number of kills (KILL), average number of days afield (DAF), average success rate (SR), average harvest rate (HR), and the average number of hunters (NH). Terminal values for the number of deer (ND50) and the number of bucks (B50) are also reported to indicate long-term equilibrium levels.

Each line of Table 6.5 represents a summary of a 50-year simulation run. The most complete measure of system performance is, of course, the actual time paths of system behavior illustrated by Figures 6.1-6.6. The computer runs to generate these figures cost less than 25¢ each and require less than a second of computer time.[4]

The advantage of concise summary reports like Table 6.5 is that many alternatives may be compared at a glance. A good policy is to use both the more detailed plots of system performance as well as the summary evaluations. The summary performance tables may be

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[4]The costs of developing a well-calibrated simulation model to yield quantitatively meaningful results can, of course, be quite substantial.

used to weed out poor designs so that more detailed analyses may be carried out on the more promising alternatives.

Table 6.5 provides a concise summary of the relative benefits and costs for a wide variety of potential management schemes. The format of presentation is quite similar to those advocated by Hill (1968) and Bentley and Davis (1967) in regard to benefit cost analyses of alternative resource development projects. Notice that the TB measure is the only one measured in dollars. Thus, the simulation approach is quite amenable to the evaluation of alternatives when not all objectives are measurable in commensurable units.

Tradeoffs in achieving different objectives under alternative schemes are made explicit in the table. Some policies which generate substantial benefits for hunters do not succeed in maintaining deer populations. Bucks-only hunts are capable of accommodating large numbers of hunters without appreciably affecting deer numbers, but few trophy bucks are produced. Clearcuts contribute to sustaining deer populations, but cost money and detract from forest aesthetics. A sample of the kinds of tradeoffs that might be examined on a simulation model like the one used here include those involving any of the following objectives:

1. Maintaining large numbers of trophy bucks
2. Maintaining high hunter success rates
3. Maintaining high deer populations
4. Maintaining stable deer populations
5. Minimizing management control and corresponding costs

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6. Providing large numbers of hunter days

7. Maintaining favorable doe/buck ratios

By expanding the model to include some of the components, users, and relationships not considered here, other benefits and costs might be explored such as highway accidents involving deer, agricultural crop damage, revenues from timber, and secondary economic benefits to communities from hunting expenditures. Including other user groups besides hunters would allow benefits and costs to be broken down to examine which groups are benefitting from each alternative. In this way equity and income redistributional questions might be explored.

Such models might include benefits of clearcutting in generating berry picking opportunities, values of trophy bucks for wildlife photographers, tradeoffs between hunters and non-consumptive deer users, impacts of clearcuts on other wildlife, and measures of forest aesthetics for different user groups. The possibilities far exceed the resources or information to carry out such studies.

While the potential for policy analysis seems great, whether the information resources, or expertise exists to develop well calibrated models to make these decisions remains to be seen. For some RCC messes, including the DFH problem examined here, preliminary models of use to policy analysis are not too far off. For very complex multiple use situations, many simplifying assumptions will be required and a great deal of research is needed.

Notwithstanding the difficulties in developing comprehensive simulation models for RCC policy analysis, the research framework su

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suggested here, which aims at the development of such models, may be able to make quite substantial contributions to the understanding and resolution of RCC problems without ever culminating in a model for policy analysis. Indeed, the principal thrust here is to examine the role of the research framework and simulation in organizing and directing research efforts and, in general, in contributing to an understanding of the RCC mess.

6.4 Contributions to RCC Research

The discussion of the potential of the simulation model for policy analysis has explored its role in evaluation and decision-making. Simulation experiments may also contribute to earlier stages in the systems approach to the research of RCC. This is part of the iterative nature of the framework.

At this point it will be useful to recall the integrative framework for interdisciplinary research and to include managers and policy makers as one of the relevant "disciplines." The potential contribution of simulation to the research of RCC lies to a great extent in its potential use as a communication medium between disciplines and between researcher and practitioner. This role will be emphasized in examining the role of simulation experiments in (1) refining the identification of the system and the corresponding model of it, (2) refining the system objectives and corresponding performance measures, and (3) generating alternative management schemes and system controls.

6.4.1 Refining the System ID and Model

Simulation experiments may contribute to system and model refinement by examining individual system components or by examining the behavior of the system as a whole. Section 6.1 examined the use of simulation experiments in the development of an individual model component. This could be carried out by an individual discipline working on a specific model.

Such experiments might indicate a need to expand the model to include additional variables or relationships or might indicate a need for greater detail in existing components. Experiments on the ecosystem model might indicate a need for a weather model to include the impact of heavy snowfall accumulations on available winter food supplies. Experiments on the hunter submodel indicate that the value of a kill, while important in determining benefits, has little effect on deer harvests.

Some behavioral characteristics of individual systems and model components do not appear except at the system level. In particular, hunter depletion of deer herds does not appear until the hunting and ecosystem model are linked to determine long-term deer population dynamics.

A primary rationale for the use of simulation models is to integrate analytical models of distinct components of complex systems in order to examine the interactions and resulting behavior of the system as a whole. By examining the response of the system to a variety of inputs, initial conditions, and parameter values, a better

understanding of the individual components and their interrelationships may be gleaned.

Expected results help to reinforce understandings of the system. The significant differences in system behavior under doe harvesting as opposed to bucks-only hunts demonstrate both the importance of doe hunting in controlling deer population levels as well as the danger of possibly depleting the herd if doe hunting is too extensive.

Unexpected results in simulation experiments lead to searches for reasons, which often lie in model assumptions or limitations, and sometimes reveal unknown behavioral characteristics of the real-world system. Analysis of such unexpected results are best performed in an interdisciplinary framework so that qualified experts within each component subsystem may attempt to isolate the cause.

Through interactions between researchers from different fields and practitioners and policy makers familiar with the real-world system, shortcomings of model components may be identified and limitations of models revealed. Also research hypotheses may be generated to empirically test relationships revealed or indicated in simulation experiments.

A major contribution of the simulation experiments on the DFH system is the identification of dynamic behavioral characteristics of the system and their relationship to management decisions, including CC decisions. The neglect of these dynamic properties of recreational environments in previous treatments may in part be attributed to the approaches.

Dynamics of the DFH System

The time paths of deer populations and food supplies in Figures 6.1–6.6 graphically demonstrate that the system is indeed dynamic. Appropriate levels for deer and hunter populations vary with the state of the system. Larger deer populations and hence more hunters may be accommodated when food supplies are plentiful. As the forest reaches maturity and food supplies become scarcer, fewer deer can be supported and excess hunting pressure may result in the depletion of the deer herd.

Both the timing and size of controls, including the introduction of deer, clearcuts, and hunting effort have significant impacts on long-term system behavior. A heavy doe hunt when deer populations are low can prevent the herd from ever developing (Figure 6.6), possibly requiring artificial stocking to reestablish the herd. Continued heavy hunting of does in a mature forest can result in a declining population (Figure 6.4). Clearcuts of 25% at 10-year intervals may result in relatively stable long-term deer populations (Figure 6.5), but alteration of the size or timing of clearcuts can lead to substantial oscillations in deer populations.

If present determinations of management and use are to include long-term impacts, these kinds of dynamic characteristics of recreation systems must be understood and taken into account when making CC decisions. Simulation experiments help to identify these characteristics and thus contribute to a better understanding of the system and the role of CC in steering the system toward management goals.

6.4.2 Refining Objectives and System Performance Measures

An important contribution of simulation experiments is in the development of valid measures of system performance. These must be based on an understanding of management objectives as well as the assumptions and behavioral characteristics of the model. The understanding of each of these may be refined through simulation experiments.

In managing resources based on long-term objectives, performance measures which reflect these objectives must be developed. The dynamic character of the system in addition to the fact that objectives themselves are imprecise and changing makes this a difficult task. Simulation experiments provide a tool for the refinement of the performance measures and the objectives themselves.

While managers may have difficulty specifying their long-term goals, when presented with time plots of system performance under alternative management schemes (like Figures 6.1-6.6) they can readily identify the advantages and disadvantages of each and determine which schemes are preferred. By working closely with managers and policy-makers and utilizing simulation experiments as a communication tool (a la the integrative model), researchers can gain insights into goal systems and develop performance measures to reflect these goals.

The long-term performance measures of Table 6.5 are only crude indicators of the achievement of long-term goals. Long-term averages give little indication of the behavior of the system in particular years or the stability of the given scheme to exogenous perturbations of the system. This is readily seen by comparing the runs of

Figures 6.1-6.6 with the corresponding summary performance in Table 6.5 (designated with an asterisk).

The development of performance measures based on objectives of maintaining stability in the system (in particular, stability with respect to heavy hunting pressure or severe winters) is an important research task. Indeed, the traditional view of RCC is really a control aimed at achieving an objective of stability (sustained yield).

6.4.3 Generating Alternative Management Schemes

The original set of management alternatives for the deer-forest-hunter system was suggested by the real-world system, where clearcutting and permit systems for doe and buck hunting are the principal controls. Simulation experiments permit the testing of a wide range of combinations and variations of these basic controls.

For policy analysis, the range of control is limited by the real-world data with which the models are calibrated or the degree of confidence the researcher has in extrapolating or interpolating with the sample data. If response of the forest to clearcutting was empirically tested for 25% and 50% levels, the researcher might extend the model to examine cuts of 33% or 75%.

The management controls involved in the simulation experiments of Table 6.5 and Figures 6.1-6.6 are quite simple. All of these schemes are basically static, representing fixed or periodic management controls. Dynamic systems can be managed more successfully to achieve their stated objectives by using dynamic control techniques. In

particular, clearcuts, hunter limitations, and doe hunts may all be determined based on the existing and expected future state of the system.

Certain behavioral characteristics of the forest system are well known and others may be revealed in simulation runs like the ones carried out in this chapter. It is well known that forests will mature with time and that food supplies and corresponding sustainable deer populations will decrease. This behavior is characteristic of all of the simulation runs. Clearcutting strategies may be set based on this information.

The system need not wait for deer populations to decline to note a need for habitat management. If clearcuts are based on drops in deer population, they will occur too late. Deer population-declines lag a few years behind the decline in food supply and the production of additional food from clearcuts lags a few years behind the actual cut. A dynamic control which monitors the food supply and determines the timing and size of clearcuts based on this information can successfully maintain stable populations by maintaining the food supply. The lag in the response of the food supply to clearcuts can be planned for so that food supplies contributed by the cut reach their peak at the appropriate time.

Such monitoring control systems may be designed to achieve most any measurable and attainable objective. Thus the control suggested above for maintaining food supplies can with enough clearcutting achieve any level short of the peak level in Figure 6.1. Similar

controls of doe harvests or hunting effort may be designed to achieve high success rates, large benefits for hunters, large deer herds, etc. Controls designed to reach unachievable goals will generally do as well as is possible.

A Simple Example of a Cybernetic Control

A simple example may help to indicate the advantages of such dynamic controls over the static controls examined in Table 6.5. Cybernetic controls use the feedback of information on the state of the system to determine the degree or type of control. Here a simple variable control of hunting effort (much like a thermostat) will be used to achieve a goal of maintaining a huntable deer population of 25. Note that in the fixed controls of Table 6.5, average huntable deer populations range from 2.3 to 30.6 deer over all hunting and habitat control options.

Notice that the goal of maintaining a fixed number of huntable deer in a dynamic system will be difficult to achieve in the absence of a habitat control to maintain food supplies. However, for illustrative purposes, only the hunting level will be allowed to vary with time. The same system and initial conditions used in the simulation experiments of Table 6.5 will be used so that comparisons may be made between the dynamic and static hunter controls.

In order to maintain huntable deer populations near 25, hunting effort will be controlled. The number of hunters permitted on the area each year will be based on the existing supply of huntable deer. The proposed control will set the number of hunters as follows:

$$NH = NHO \times (NDVUL/25)^2$$

where NHO is a fixed parameter indicating the desired level of hunting effort (possibly the number of permit applications expected) and NDVUL is the number of huntable deer. Notice that NH will be set larger than NHO if NDVUL exceeds 25 and will be less than NHO if NDVUL drops below 25. The term NDVUL/25 is squared to make it more responsive to deviations from 25.

Each of the clearcutting and doe vulnerability controls of Table 6.5 were tested with the dynamic hunter control and the results are shown in Table 6.6. The column of particular interest is NDVUL. Note that over all combinations of clearcutting and doe hunting controls, the dynamic controller is more successful in maintaining huntable deer populations near 25. In cases where the fixed controller resulted in severe depletion or even extinction of the herd, the dynamic controller maintains huntable deer populations in excess of 15 deer. Correspondingly, annual kills, success rates, and harvest rates are also stabilized.

In particular, if managing for success rates, the dynamic controller maintains averages between .06 and .10 over all tested combinations of other controls. Clearcutting and doe harvesting strategies could be selected from Table 6.6 to complement the dynamic hunter control.

The improvement in stabilizing the number of huntable deer is, of course, not achieved without sacrifices. Note that the levels

Table 6.6 Performance of Alternative Management Systems: Dynamic Control

CUT	NHO	VDOE	ND	NDVUL	KILL	DAF	SR	HR	TB	NH	ND50	B50
0.00	40.	0.00	70.9	21.7	3.0	127.5	.08	.12	2.8	33.1	54.	16.
0.00	60.	0.00	72.3	21.0	3.9	177.6	.07	.16	3.8	46.1	55.	15.
0.00	80.	0.00	72.8	20.3	4.6	220.3	.07	.20	4.6	57.1	55.	14.
0.00	100.	0.00	73.2	19.7	5.1	259.0	.07	.23	5.2	67.0	55.	13.
0.00	120.	0.00	73.5	19.2	5.5	294.7	.07	.26	5.8	76.2	55.	13.
0.00	140.	0.00	73.8	18.7	5.9	328.0	.06	.28	6.3	84.7	55.	12.
0.00	160.	0.00	74.1	18.3	6.2	359.3	.06	.31	6.8	92.7	55.	12.
.25	40.	0.00	80.8	24.1	3.9	154.2	.09	.14	3.5	40.2	73.	20.
.25	60.	0.00	81.5	23.0	4.9	210.3	.08	.19	4.6	54.6	74.	18.
.25	80.	0.00	82.1	22.1	5.7	259.6	.08	.23	5.5	67.3	74.	16.
.25	100.	0.00	82.5	21.4	6.3	304.0	.07	.27	6.3	78.7	74.	15.
.25	120.	0.00	82.9	20.8	6.8	344.8	.07	.30	6.9	89.2	74.	14.
.25	140.	0.00	83.2	20.3	7.2	382.9	.07	.32	7.6	99.0	74.	13.
.25	160.	0.00	83.5	19.9	7.6	418.6	.06	.35	8.1	108.1	74.	12.
.50	40.	0.00	77.5	23.3	3.5	144.8	.08	.14	3.3	37.7	71.	19.
.50	60.	0.00	77.9	22.2	4.5	197.1	.08	.18	4.3	51.2	71.	17.
.50	80.	0.00	78.1	21.4	5.1	242.4	.07	.22	5.1	62.8	71.	16.
.50	100.	0.00	78.3	20.7	5.7	283.0	.07	.25	5.8	73.3	71.	15.
.50	120.	0.00	78.4	20.1	6.1	320.3	.07	.28	6.4	82.8	70.	14.
.50	140.	0.00	78.6	19.6	6.5	355.4	.07	.30	6.9	91.8	70.	13.
.50	160.	0.00	78.7	19.2	6.9	388.3	.06	.33	7.4	100.2	70.	12.
0.00	40.	.50	54.8	26.5	5.3	188.7	.09	.17	4.6	49.4	37.	11.
0.00	60.	.50	49.6	23.6	5.5	225.2	.08	.20	5.1	58.6	32.	10.
0.00	80.	.50	45.8	21.6	5.5	250.7	.07	.22	5.4	65.1	28.	9.
0.00	100.	.50	42.8	20.0	5.5	269.7	.07	.24	5.5	69.9	26.	8.
0.00	120.	.50	40.3	18.8	5.4	285.0	.06	.25	5.6	73.8	24.	7.
0.00	140.	.50	38.3	17.7	5.3	298.0	.06	.26	5.7	77.0	22.	7.
0.00	160.	.50	36.8	17.0	5.2	311.0	.06	.27	5.8	80.3	22.	6.
.25	40.	.50	52.5	25.6	4.6	173.3	.09	.16	4.1	45.3	42.	12.
.25	60.	.50	49.4	23.5	5.2	219.7	.08	.20	4.9	57.1	40.	11.
.25	80.	.50	47.6	22.4	5.7	261.0	.08	.23	5.5	67.8	38.	10.
.25	100.	.50	46.5	21.5	6.2	301.4	.07	.26	6.2	78.1	37.	9.
.25	120.	.50	45.5	20.8	6.5	336.5	.07	.29	6.7	87.1	35.	8.
.25	140.	.50	44.4	20.1	6.8	366.7	.07	.31	7.2	94.8	34.	8.
.25	160.	.50	43.5	19.5	6.9	393.3	.06	.33	7.5	101.6	33.	7.
.50	40.	.50	55.0	25.7	5.0	185.4	.09	.17	4.4	48.4	51.	14.
.50	60.	.50	53.6	25.3	6.1	249.2	.09	.22	5.7	64.9	48.	12.
.50	80.	.50	52.4	24.2	7.0	303.3	.08	.27	6.6	78.9	46.	11.
.50	100.	.50	51.1	23.2	7.5	348.0	.08	.30	7.3	90.3	44.	9.
.50	120.	.50	49.7	22.3	7.8	384.9	.07	.33	7.9	99.8	42.	9.
.50	140.	.50	48.3	21.5	8.0	416.1	.07	.35	8.3	107.7	40.	8.
.50	160.	.50	47.0	20.7	8.1	442.3	.07	.37	8.6	114.4	39.	7.
0.00	40.	1.00	35.2	23.1	3.7	144.2	.08	.13	3.3	37.6	22.	8.
0.00	60.	1.00	32.1	20.8	3.8	173.5	.07	.16	3.7	44.9	20.	7.
0.00	80.	1.00	29.8	19.2	3.8	194.2	.07	.18	3.9	50.2	19.	6.
0.00	100.	1.00	27.9	17.9	3.8	209.3	.06	.19	4.0	54.0	18.	6.
0.00	120.	1.00	26.3	16.8	3.7	220.5	.06	.20	4.1	56.8	17.	5.
0.00	140.	1.00	25.0	15.9	3.6	229.4	.06	.21	4.1	59.0	16.	5.
0.00	160.	1.00	23.8	15.1	3.5	236.8	.05	.21	4.2	60.8	15.	5.
.25	40.	1.00	41.6	26.8	5.0	185.3	.10	.17	4.4	48.4	33.	10.
.25	60.	1.00	37.7	23.9	5.1	220.1	.08	.20	4.8	57.1	30.	9.
.25	80.	1.00	34.6	21.8	5.0	241.9	.08	.22	5.0	62.6	27.	8.
.25	100.	1.00	32.1	20.1	4.9	257.1	.07	.23	5.1	66.4	25.	7.
.25	120.	1.00	30.1	18.7	4.7	268.3	.07	.24	5.1	69.2	23.	7.
.25	140.	1.00	28.4	17.6	4.5	276.8	.06	.25	5.1	71.2	21.	6.
.25	160.	1.00	26.9	16.7	4.4	283.8	.06	.25	5.1	72.9	20.	6.
.50	40.	1.00	44.6	28.4	5.8	207.0	.10	.19	5.0	54.1	39.	11.
.50	60.	1.00	39.7	25.0	5.7	239.2	.09	.22	5.3	62.2	34.	10.
.50	80.	1.00	36.1	22.5	5.5	258.5	.08	.23	5.4	67.0	30.	8.
.50	100.	1.00	33.2	20.7	5.2	271.2	.07	.24	5.4	70.1	27.	8.
.50	120.	1.00	31.0	19.2	5.0	280.3	.07	.25	5.4	72.3	25.	7.
.50	140.	1.00	29.1	18.0	4.8	287.4	.06	.26	5.3	74.0	24.	6.
.50	160.	1.00	27.6	17.0	4.6	293.2	.06	.26	5.3	75.4	22.	6.

CUT = percent clearcut
NHO = desired number of hunters
VDOE = doe vulnerability
NDVUL = number of huntable deer
KILL = deer harvest
NH = actual number of hunters
ND50 = terminal deer population
B50 = terminal buck population

for NHO set in the controller are not always achieved. The NH column gives the average number of hunters per year allowed under the dynamic control. Those clearcutting and doe hunting controls which are least productive in terms of deer populations achieve higher huntable deer numbers in the dynamic control by limiting the hunting effort. Such limitations on hunters might not be politically feasible. Thus the researcher might be required to construct a different controller which allowed greater numbers of hunters and still maintained deer herds. This would require more intensive clearcutting and more doe restrictions.

A better picture of the effect of the dynamic control on the system is seen in Figure 6.7 where a 50-year graph of the system behavior is shown. Figure 6.7 shows the dynamic control with NHO = 60 and with a 50% doe vulnerability and no cutting. It corresponds to the static control of Figure 6.4. Notice that in the mature forest the dynamic control brings the deer population nearly into equilibrium while the fixed control is harvesting does too heavily and the deer population is declining quite rapidly.

This is only one simple example of what can be done with dynamic controls. Extremely complex systems of controls may be developed and tested to attempt to simultaneously achieve a number of objectives. Controls which monitor system states and adjust the scale and kind of control will be much more responsive to exogenous perturbations of the system. Testing alternative control schemes by simulation experiments will suggest refinements in management control.

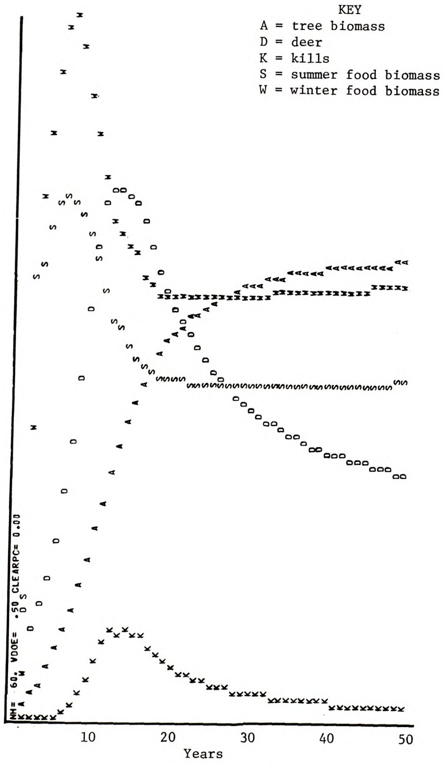

Figure 6.7 -- Partial Doe Hunt with a Dynamic Hunter Control

Such dynamic controls begin to close the information feedback loops described in the general systems model and point toward a cybernetic monitoring and control management structure.

CHAPTER 7

EVALUATION AND CONCLUSIONS

The objective of this dissertation was to clear up what was termed the recreational carrying capacity (RCC) mess. More specifically the development of a more precise definition of the term and a systematic general framework for organizing research efforts was proposed.

Part I of this study presented the integrative model for interdisciplinary research in the RCC context. A conceptual model of a general recreation resource utilization system was presented and the CC concept was defined in this context. The model provides a classification of the relationships involved in RCC and suggests a framework for organizing RCC research along disciplinary lines. Chapter 3 briefly presented General Systems Theory as a suggested set of meta-tools to complete the analytical component of the research framework.

Part II began the process of carrying out the research framework on a hypothetical Deer-Forest-Hunter system. The experience with the DFH system provides an initial basis for making preliminary evaluations of the proposed framework and some general conclusions about RCC. The limitations of attempting to carry out a comprehensive multidisciplinary study in a one-man dissertation should be kept in mind. The application to the DFH system was in many ways a simulation itself

(of the integrative research process), only intended to indicate the suggested research process, not to be a complete example.

In evaluating the proposed research framework, the experience with the DFH system will be supplemented by subjective evaluation of the internal consistency of the framework, its ability to incorporate existing theory and research results, and the generalizability of the DFH experience to other RCC messes.

A basic assumption in developing the integrative research framework is that complete knowledge of recreation resource systems will never be achieved. This is in part due to their complexity, and in part a result of their dynamic character. The conceptual model and meta-tools proposed in this dissertation are only meant to be the initial stage of what should be a continual process of refinement. Indeed, it is actually an intermediate stage as all of the preceding research was necessary to achieve the synthesis proposed here.

The integrative framework provides for continual feedback from individual disciplines (including recreation managers) to the research model to refine the conception of RCC as well as the tools and models used to resolve individual problems within the RCC mess. This has always been the ideal, but has been difficult to achieve in the absence of a comprehensive organizational model. This study has attempted to direct some attention to these "organizational problems" of research and to provide a suggested framework for organization of RCC research.

The iterative nature of the model should be kept in mind in evaluating its potential contribution to RCC research, according to the seven criteria set forth in Chapter 1. The question is not whether this dissertation has completely resolved all of the RCC and RCC research problems, for it surely has not. The question is whether or not the research framework presented here provides a good start and allows for cumulative progress toward the goal of understanding and resolving problems related to RCC.

7.1 Its Contribution to Clarifying What RCC Means

The attempt to incorporate dynamics, management, objectives, and a myriad of other factors into the RCC concept may have resulted in more confusion than understanding of the term. This author's and others' attempts to broaden the concept of RCC are really attempts to elevate the concept from a suboptimizing one to a comprehensive one. The resulting concept is so divorced from traditional meanings and connotations of the term, that it no longer applies. It appears that the RCC concept should have been abandoned early in this study and replaced by a broader comprehensive recreation management framework.

The RCC mess is just a part of a larger recreation resource management decision system, namely, that part that involves the use decision. Other parts include scale, design, location, and other assorted management decisions, all of which contribute to the success in achieving the system objectives. Once RCC is viewed in this broad management framework, it cannot be defined except in relation to it.

The experience with the DFH system should be sufficient to illustrate the interrelatedness and dynamic character of management decisions. In the light of the wide variation in the behavior of the DFH system under alternative management and stocking schemes (as seen in Figures 6.1-6.7 and Tables 6.5 and 6.6), the question of what is the CC of the area for deer or hunters is rather meaningless.

The relevant question is "which of the alternatives represented in Figures 6.1-6.7 or the infinity of other possibilities is desired?" In particular, the use decision cannot be separated from all of the other decisions in regard to the management of the area.

The traditional view, and perhaps the only possible view, of RCC is to fix all variables except one (use) and then determine the maximum value of that remaining variable consistent with overall system objectives. Thus, managers decide in advance to clearcut 25% every 10 years, not to hunt does, and then set use levels (CCs) based on these constraints. This is the essence of suboptimizing, appropriately defined by Boulding to be "finding out the best way to do something which should not be done at all."

The simulation experiments on the DFH system illustrate that use decisions must be made within a comprehensive management decision-making framework. The relationships between the numbers of deer and hunters, and the other possible management controls are part of this framework. Carrying the term RCC, with all of its past misunderstandings, into this framework only leads to more misunderstanding and confusion.

This author advocates the use of two separate terms. The traditional RCC term should remain a suboptimizing one. As such, it has limited value as a lever to begin study of complex systems by assuming interactions between variables are negligible and that management decisions can be made independently.

The comprehensive concept will be termed "the use decision." Notice that there is no implied maximum or capacity in this concept. The use decision involves the determination of what use level is best under the given circumstances at a given time. Use levels below a given "best" level are misallocations (of use or resources) just as use levels which exceed it are. There is waste in both over- and under-utilization.

The crux of this thesis is that the use decision must be treated within a broad management framework. In particular, tradeoffs, dynamics, objectives, and other dimensions discussed in relation to CC are more appropriately applied to the use decision, viewed as one of a "mess of decisions" making up the management subsystem.

The systems model of a recreation resource utilization system contains this management subsystem and depicts how this management subsystem interacts with the user and resource subsystem. Thus, the systems model appears most appropriate for examining the use decision in a comprehensive management decision-making system context.

It is hoped that this distinction between RCC and the use decision helps to clear up the RCC mess and to guide research toward more comprehensive study of how the use decision fits into the larger management framework and away from searches for simple answers through suboptimizing approaches to RCC.

7.2 The Success in Including Dynamics, Tradeoffs, and Multiple Objectives

The success in including such dimensions into the DFH study should provide sufficient evidence that this is one of the principal strengths of the proposed research framework. The choice of systems and simulation techniques leads naturally into the prominent role of time and the ability to include multiple objectives. The quantification of objectives in the form of performance measures and the ability of simulation to yield displays of multiple performance measures allow explicit consideration and identification of tradeoffs between objectives and between different user groups.

7.3 The General Applicability to RCC Messes

A framework was desired which would be equally applicable to wilderness environments, urban parks, lakes, campgrounds, and other potential areas of RCC study classified by resource or activity. The DFH application gives some idea of the general applicability of the framework, as both deer and hunters are treated within the same framework. The framework can embrace both the recreational and wildlife CC concepts. Limited consideration of including wildlife photographers and berry pickers within the same model were also discussed.

The general "meta-treatment" of CC in Chapter 2 and the use of meta-tools from General Systems Theory also speak for the general applicability of the framework. Twenty years of experience with

systems techniques has shown them to have broad applicability (McLeod, 1974).

While the author has restricted applications to the DFH system, the reader is urged to consider analogues of each of the relationships and concepts illustrated for the DFH system in other kinds of recreation systems. The general systems model and ninefold classification of interactions provides a structure for examining isomorphisms between different kinds of CC problems. Only by applying this framework to a wide variety of resource and activity types can its full generalizability be tested, but the experience here with the DFH system and the applications of similar techniques to water-based recreation (Hammon, 1974) and wilderness environments (Smith and Krutilla, 1976) provide strong evidence of its potential for other types of environments and activities.

7.4 Its Research Organizing Abilities

The systems model and ninefold classification of interactions is the principal device for organizing research efforts. It may be evaluated based on the experience with the DFH system as well as its ability to organize existing research dealing with other RCC messes.

In the DFH case, the systems model and approach provided a systematic organizational framework with which to approach the complex system. The use of the ninefold classification of interactions facilitated the identification of important relationships in Chapter 4 to begin the modeling process. The classificatory nature of the framework helped to ensure a comprehensive look at the problem.

Possibly more important than the identification of those relationships included in the model, is the ability of the framework to reveal missing components and indicate their relationship to the part of the system that has been modeled. It is clear in the DFH system model that only a single user group is included. Timber, agricultural, and other recreational interests fit easily into the model by expanding the user subsystem and adding corresponding sets of interactions. Similarly additional components of the resource subsystem might be considered.

A broader test of the organizational abilities of the model is its ability to classify existing RCC efforts. It is left to the reader as a simple exercise to take the RCC literature on any resource or activity, or the bibliographies of Stankey and Lime (1973) or Butler (1972), and classify the entries according to the ninefold grouping of interactions.

The key distinction between the system classification and those which have appeared to date (such as the above two bibliographies) is that the focus is on the interactions and not the subsystems. This identifies relationships between objects as the key to RCC research, not the objects themselves. The fact that these interactions coincide to a great extent with disciplinary interests helps to direct research to the appropriate field.

In addition to the nine classes of interactions, other research areas identified as important for RCC include research into the determination of objectives, decision-making with multiple objectives,

dynamics of recreation systems, and more precise identification of recreation systems. Meaningful classification of users and resources is important to complete the systems model.

7.5 Ability to Facilitate Interdisciplinary Communication

The ability of the framework to facilitate interdisciplinary research must be based on logical grounds. A dissertation, being a one-man effort, cannot capture the essence of interdisciplinary research. The application to the DFH system was necessarily one person's effort to integrate models and information from a number of different disciplines. The full potential of the framework to stimulate research by providing a vehicle for communication cannot be seen except by using the framework in conjunction with an interdisciplinary team. In a dissertation this is not possible.

An attempt, although somewhat artificial, was made to illustrate the potential workings of the integrative model in the development of the hunting model. Here contributions from recreation, wildlife management, and economics to the valuation of hunting were reviewed. In the framework of the systems model to determine CC these were found lacking in that values derived had little use for management except to justify expanded wildlife programs. A refined research problem requiring valuations of individual hunting experiences including quality considerations and able to make behavioral predictions was formulated. The author, assuming the role of a resource economist, presented a general model which incorporated some of these

considerations. The economic orientation added concepts of diminishing returns and probability to the hunting valuation model.

The model was revised to be incorporated into the systems framework and then evaluated. It is at this point that inputs from other disciplines like wildlife management, sociology, and recreation could be useful in evaluating and refining the model. The systems model is meant to be tested, compared, evaluated, and refined in conjunction with those of other disciplines. The simulation experiments could only provide an indication of this process.

A basic problem in interdisciplinary research efforts is communication. Whether the systems model and approach provides a vehicle for such communication remains to be seen. One drawback may be the misunderstanding which exists about systems and an anti-systems bias which has developed among some researchers and managers as a result of poor application or misinterpretation of past systems efforts in the social sciences (Meta Systems, 1975, p. 386). A small core of "systems jargon" must be diffused and adopted by researchers, however this only involves a small set of terms, many of which are already well understood. There always exists a natural resistance to attempts by new or existing fields to infringe on the territory of others or to "push" a new approach. If systems techniques and the approach suggested here are presented as attempts to integrate information from many disciplines rather than falsely pretending to be offering something entirely new, they may be more successful in providing a basis for interdisciplinary communication.

The integrative approach presented here attempts to preserve the integrity of the individual disciplines. Thus it should present no threat to established fields of study. It is only suggested that individuals within each discipline interested in interdisciplinary kinds of studies (and in particular recreation resource management) adopt a common set of terms and a common comprehensive view of the problems at hand. The systems model for resource CC is presented as such a common model.

7.6 The Feasibility of Carrying Out Such a Framework

The basic question here is whether or not systems techniques are applicable to recreation management problems,[1] and whether the existing structure of the recreation research community permits such applications to be carried out. The applicability of systems techniques to recreation may be judged on the basis of the history of systems techniques in other areas of study.

Systems techniques were first applied to military, space, and communications problems with considerable success (von Bertalanffy, 1968). Here the problems were complex, but goals were clearly defined and individual components fairly well understood. Initial attempts to apply these techniques to social and economic problems have resulted in mixed success.

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[1]Watt (1964) and Cesario (1973, 1975) discuss the applicability and suitability of systems techniques in recreation and general resource management.

Meta Systems Inc. (1975, p. 15) in a comprehensive review of systems techniques in water resources planning claims that "water resource problems are intermediate between traditional systems problems and social problems." The kinds of problems encountered in recreation would seem to closely parallel those of water resource development, involving interactions between resources and users and multiple objectives. Thus, Meta Systems conclusion (p. 361) that "the evidence is overwhelmingly in favor of the use of the systems approach" in the water resource planning context, would seem to offer great promise to recreation as well. The success of the Harvard Water Program (Hufschmidt, 1966) and the series of river basin studies that it fostered (Hamilton, 1969) adds additional encouragement.

It is too early to judge the success of the Wilderness Trip Simulator or the Boating CC model of the North Carolina Study, the two major simulation projects in the RCC area to date. Published results (Smith and Krutilla, 1976; and Hammon, 1974) indicate that the former has been more successfully completed, but one should be wary of judging the merits of the approach based on the final products. In many cases the research questions and answers generated along the way may be the primary contributions of such studies.

Two factors inhibit the application of the research framework presented here, and more generally the application of systems techniques in recreation.

1. Lack of training of recreation researchers in quantitative and systems techniques severely limits their ability to assume the role

as the developers, organizers, and integrators at the core of the integrative model. Modeling skills are in short supply among recreation researchers. This is evidenced by extensive reliance on canned computer routines and linear models in recreation research. The attempts to apply quantitative techniques to recreation have largely been made by researchers not directly associated with the field, as evidenced by the RCC literature (Penz, 1975; Menchik, 1973; Anderson and Bonsor, 1974; Fischer and Krutilla, 1972; Schuler and Meadows, 1975; V. Smith 1974; Romesburg, 1974).

Recreation researchers are the logical candidates to assume the role of putting together research results, refining research problems, and communicating with formal disciplines. USDI BOR (1974) recommends that recreation researchers be exposed to a broad spectrum of disciplines including the "integrative" disciplines like systems analysis. Such training would permit recreation researchers to assume the role advocated here.

2. The organizational structure of the recreation research community does not readily facilitate the integrative structure advocated here. With the exception of USFS research teams, there are no centers for long-term, large-scale, comprehensive, interdisciplinary recreation research. Such a national center has been advocated many times (National Academy of Sciences, 1969; USDI, BOR, 1974) but has never been established. There are no "think tanks" for recreation. Organizations like Resources for the Future Inc. could assume this role, but must have a continuing commitment to recreation research.

Traditional sources of funding for recreation research have been local, dictating specific, short-term research efforts (USDI, BOR, 1974, p. 81). Long-term funding for general comprehensive studies have been rare in recreation. Recreation has not traditionally been looked on as a research area of importance equal to that of other resource areas, such as timber, water, and minerals. Long-term funding is required for the kind of research framework advocated here.

Problems of putting together and organizing interdisciplinary research teams has not been explicitly discussed in this study.[2] In fact, actually assembling such a team is not necessary to carry out the framework. All that is required is a central organizing body to communicate results and problems to respective disciplines through an organizational framework like the one proposed here. The stimulus to researchers in the field may be research grants or simply interest in recreational problems.

7.7 The Applicability of the Results to Management

Given the applied nature of most recreation research, this may be the most serious question. The thrust of this dissertation has been toward research, not management. A legitimate question is, "is the result of the proposed research framework of any use to managers?" The contribution of the resulting model may be discussed at two levels, depending on the effort put into the calibration of the simulation model

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[2]See Mar (1973) for a discussion of interdisciplinary team coordination problems in simulation model development.

and the resulting degree of confidence in the quantitative outputs of the model.

First, the possible contribution of the "quick and dirty" simulation model of the DFH system may be examined. The primary use of such models is to raise questions and direct research efforts; however, managers can also benefit if they are included as one of the "disciplines" in the integrative framework. Chapter 6 demonstrated the potential for refining managers' understanding of the DFH system and their own objectives in managing it. Through simulation experiments managers can explore impacts of alternative management schemes, identify dynamic characteristics of recreation systems, and explore tradeoffs between achieving different objectives.

The role adovcated here for such "uncalibrated models" in management and policy analysis is for decision-makers to "play" with the model to gain a better understanding of the systems with which they deal. Model results may be tempered by understandings of the real-world system. This management gaming use of the model is primarily an educational one, both for the manager and the researcher. Managers and policy analysts should then put the model down and make decisions based on their understandings of the real-world system, which hopefully has been improved by the stimulation afforded in the management gaming exercises.[3]

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[3]Smith and Krutilla (1975) claim that this has been the primary use to date of the wilderness trip simulator.

By including managers from the beginning in applying the framework presented here, benefits in understanding of recreation systems may be gained at each step by manager and researcher alike. Such a scheme does not require completion to be successful. Given the dynamic nature of recreation systems and problems it is unlikely that any research efforts or understandings are ever complete; so it is quite foolish to expect all of the benefits of a research program to come from the final product.

The integrative framework aims at a cumulative research program. Thus an incremental approach to model development and refinement may be pursued. There is no need to advocate well calibrated, complete simulation models for each recreation management problem. What might be asked here is that if the research framework is carried through to completion then will the product be of any use to management.

The potential uses of a well-calibrated comprehensive simulation model should be apparent. The management and policy implications of such a model were explored in Section 6.3. A well-calibrated model adds significance to the quantitative outputs of simulation experiments. Given precise knowledge of objectives, benefits, costs, and system behavior, alternative management and use schemes could be tested and "optimal" strategies could be selected based on the performance measure outputs.

A basic question in research into recreation systems is whether precise knowledge or agreement about values and objectives can ever be attained. Also it must be remembered that objectives

as well as the system itself are constantly changing. The integrative model is especially designed to meet these problems as it provides for constant iteration and refinement of models and tools. Just as the controls of the simulation model are designed to steer that system toward management objectives, the integrative model attempts to steer research programs toward their objectives (one of which might be to generate information useful to managers). Such a research program is itself a cybernetic system designed to satisfy managers, researchers, and others. Looked at in this way, with managers as one of the disciplines involved in the integrative model, the framework presented here can become one designed to serve managers.

APPENDICES

APPENDIX A

A BRIEF SUMMARY OF SOME GENERAL SYSTEMS CONCEPTS

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A BRIEF SUMMARY OF SOME GENERAL SYSTEMS CONCEPTS

This section is intended to introduce the reader to some commonly used systems terminology and principles. For more detail, the reader is referred to Laszlo (1972), Churchman (1968), or Bertalanffy (1967). Glossaries of systems terms are presented in McLeod (1974) and Schoderbek (1975).

A _system_ is a "set of objects together with relationships between the objects and between their attributes" (Hall and Fagan, 1965). The emphasis in the systems view is on the relationships, or interactions, between the various system components and how these interacting components "add up" to the whole system.

Systems are generally viewed within an _environment_. "For a given system the environment is the set of objects a change in whose attributes affect the system and also those objects whose attributes are changed by the behavior of the system" (Hall and Fagan, 1956). The separation between system and environment is not clearcut and depends on the purpose of the study.

Within a given system one generally identifies several _sub-systems_. These are systems in themselves (i.e., sets of objects of the system) such that interactions within the subsystem are strong and those with the rest of the system are weak. Thus, a similar relationship exists between system and subsystem as between environment and

system; the system essentially being the environment for the subsystem when the subsystem is viewed as a system in itself.

Systems are often divided into two categories, open systems and closed systems, according to whether or not there exists a significant interchange of energy, materials, or information between the system and its environment. Closed systems obey the second law of thermodynamics, increasing in entropy, becoming less structured, and more random. Such systems are rare in the real world, and thus it is open systems which have received the major emphasis. Open systems are negentropic, elaborating structure and gaining information over time. The interchange of materials, energy, and information at the system boundary (between system and environment) is a significant component of such systems.

Cybernetics, the science of communication and control, is one of the earliest branches of general systems theory (GST). Founded and named by Norbert Wiener from the Greek word meaning "steersman," it studies how systems regulate, reproduce, and organize themselves. In short, how do systems control themselves? A control is a "natural or constructed subassembly which interacts with its environment to bring about a particular stability called the goal or objective of the system" (Pask, 1961).

Control systems are characterized by feedback processes, of which there are two general types:

1. Negative feedback (morphostasis, system cybernetics I). These are error correcting, deviation controlling processes in which

the system typically monitors deviations from a given goal and adjusts the system behavior accordingly. The thermostat is a widely used example.

2. Positive feedback (morphogenesis, system cybernetics II). Positive feedback involves deviation amplifying, organization elaborating processes. Examples include processes which exhibit exponential growth, as well as evolutionary processes where systems adapt through a process of natural selection.

Von Bertalanffy describes two principles which apply in general to complex open systems: (1) The principle of equifinality--the same final state of an open system may be reached by different paths; and (2) the principle of multifinality--similar initial states may lead to dissimilar end states. These two principles are particularly relevant to social science research into complex open systems to determine causal relationships via reductionist approaches as they demonstrate that such approaches will generally fail.

Laszlo (1972) summarizes GST by four principal properties common to all complex systems: (1) the concept of wholeness, or "systemness," (2) system cybernetics I (negative feedback), (3) system cybernetics II (positive feedback), and (4) hierarchy. All but the last property have been mentioned above. Most complex systems exhibit hierarchical structure of some kind: "A hierarchic system is a system composed of interrelated subsystems, all of which are ranked and ordered such that each is subordinate to the one above it, until the lowest elementary

subsystem level is reached" (Schoderbek, 1975). Simon (1969) proposes a rationale for this property of complex systems, in terms of natural selection.

APPENDIX B

THE ECOSYSTEM MODEL

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THE ECOSYSTEM MODEL

The ecosystem model is based on the management gaming model of Walters and Bunnell (1971). The model has been simplified somewhat here. Figure 5.1 shows that the ecosystem model consists of four major blocks: (1) a plant growth model, (2) a deer food production model, (3) a deer feeding model, and (4) a deer population model. These will be described in turn.

Plant Growth and Competition

Plants are broken down into two major groups: (1) shrubs and grasses (SHRUBS), and (2) all tree species (TREE). This division is aimed primarily at distinguishing the transition in forest succession from grasses to shrubs to immature forest to mature forest and the corresponding effect on deer food supplies.

Since the biomass of a tree and corresponding available food for deer can largely be determined from the age of the tree,[1] the tree group is broken down into yearly age sub-groups (TREE(I), I = 1, ... 20) and the model is set up for a forest which matures in 20 years so that the final group includes all trees older than 20 years.

The state of the tree growth in the forest is represented by measures of the numbers of trees of each age (TREE(I)) as well as a

[1]Differences in deer food production among different tree species are included in the parameters DEL(I).

single measure of the total biomass of all trees (BIO(1)). This biomass is calculated as a weighted sum of the measures of the numbers of trees in each age class.

$$BIO(1) = \sum_{i=1}^{20} GAM(I) \times TREE(I) \qquad (B.1)$$

The weight GAM(I) is the estimated mass of the average tree of age I in the study area, and TREE(I) is a measure of the number of trees of age I.

The second plant group, SHRUBS, is not further subdivided. Its state at any time is represented by a single measure BIO(2), the total dry weight biomass of all grasses and shrubs.

The production model for both plant groups is based on the Gause (1935) model of competition between animals. Walters and Bunnell (1971) use the model to simulate plant growth. In its most general form the production of N different plant groups is determined by two sets of parameters, one for the productivity of the area for each of the N species, and another for competition between the plant groups. The competition coefficients A(I,J) represent the degree of competition between species I and species J for light, groundspace, water, etc. The rate of production of species I is given by

$$P(I) = \begin{cases} p_I \times BIO(I) \times \left[1 - \sum_{j=1}^{N} A(I,J) \times BIO(J) \right] \\ \text{or 0 if the above quantity is less than zero,} \end{cases}$$

where BIO(I) is the current biomass of species I and p_I is the maximum productivity of the area for species I under optimal conditions.

Here the model is simplified by letting $N = 2$. Finer breakdowns of plant groups would be desirable but make parameter estimation difficult and are unnecessary for the purposes here. Although production parameters can be estimated from field data, competition coefficients must be set by iterative techniques. That is, coefficients are varied until reasonable response patterns are achieved.

The production of TREEs and SHRUBS are distinguished in this model. Most of the mass of trees remains over the winter period while SHRUBS experience substantial die downs. For this reason, tree biomass, BIO(1) is treated as constant throughout the year and only updated each spring, after ages have been increased, natural losses taken, and new saplings produced. Survival rate parameters B(I) determine how many trees of each age advance into the next.

$$\begin{aligned} \text{TREE}(I) &= B(I-1) \times \text{TREE}(I-1) \\ \text{TREE}(20) &= B(20) \times \text{TREE}(20) + B(19) \times \text{TREE}(19) \end{aligned} \qquad (B.2)$$

New saplings are produced according to the Gause model:

$$\text{TREE}(1) = \begin{cases} P_1 \times \text{BIO}(1) \times \left[1 - \sum_{j=1}^{2} A(1,J) \times \text{BIO}(J) \right] \\ \text{or 0 if the above quantity is less than zero,} \end{cases} \qquad (B.3)$$

where the biomass BIO(1) can be viewed as representing the amount of seed left over winter to generate new growth in the spring. The Gause model limits growth by the summation term in equation B.3 which

represents the amount of competition from already existing trees and shrubs.

Production and attrition of shrubs and grasses takes place during each time period. During the growing season (April-October) the Gause model is used to determine rates of production of SHRUBS by the formula

$$\frac{d\ BIO(2)}{dt} = \begin{cases} P_2 \times BIO(2) \times \left[1 - \sum_{j=1}^{2} A(2,J) \times BIO(J)\right] \\ \text{or 0 if the above quantity is less than zero.} \end{cases} \qquad (B.4)$$

Losses due to deer feeding (to be described shortly) must also be subtracted. During the fall die-down, 90% of SHRUB biomass is lost; i.e., BIO(2) becomes .10 x BIO(2).

Deer Food Production Model

Food production for deer comes from both the TREE and SHRUB plant groups. For the SHRUB group, all biomass is considered as potential food for deer. Hence equation B.4 above describes the food production from SHRUBS. TREE food production is modeled differently and distinguished from biomass.

Food production potential for TREEs is calculated each spring as a weighted sum of the tree counts for each age group and this constant increment in tree food is added each month of the growing season.

$$\text{Tree food production} = \sum_{j=1}^{20} DEL(I) \times TREE(I)$$

where weights DEL(I) represent the amount of food produced per month by a tree age I. Availability of this food to deer is also considered to take account of food which may be out of reach for deer. Thus younger trees are more heavily weighted than mature trees.

As in the case of SHRUBS, a fall die down in the food produced by trees reduces the amount available over winter. Food production from both groups are added together to determine the total available food for deer.

Deer Feeding Model

The deer feeding model uses a Holling (1966) disc equation. All deer are assumed to have uniform preferences for the two food groups. S(1) is the preference for food from trees and S(2) is the preference for SHRUBS and grasses with $S(1) + S(2) = 1$. Constants D(I) are used to adjust food intake for the five different age groups. Younger animals intake considerably less than older ones. Data from Short (1972) has been used to estimate these parameters.

The rate of food intake of food group K by a deer of age I is given by

$$DELFD(I,K) = \frac{AFD \times S(K) \times BIOFD(K) \times D(I)}{1 + BFD \times (S(1) \times BIOFD(1) + S(2) \times BIOFD(2))}$$

where AFD, BFD are food intake parameters,

BIOFD(1) is the amount of tree food available,

BIOFD(2) is the amount of food from SHRUBS and grasses,

S(K) are the preferences for the two food groups, and

D(I) are weighting parameters to adjust for deer age.

This model allows the deer to select the food types they prefer according to the availability of both food types. Here the parameters S(K) are assumed constant, although empirical data indicate they may vary with the season. If both species of food are in unlimited abundance, the rates of intake will be S(1) x AFD/BFD and S(2) x AFD/BFD for the two groups. If one or the other food type becomes scarce the model responds with deer changing from the scarce food to the more abundant one.

These intake rates are then multiplied by the number of deer of the corresponding age groups and summed to determine total food intake. These amounts then reduce the food available from each of the plant groups. One important food intake status variable is the sum of food intake over the winter months, denoted YRFD(I) for deer age group I. This variable is used to determine spring birth rates.

Deer Population Model

Each spring deer age structure is updated and new fawns are produced. Reproduction rates depend on the age of the does, the herd density, and food intake in the previous winter. Early mortality of fawns is considered as a component of the birth rates.

The age dependency of the birth rate is included by specifying maximum reproductive rates RMAX(I) for does of age I. These have been estimated from data in Walters and Bunnell (1971). Herd densities can reach levels so that social inhibition of breeding occurs regardless of the food supply. This is modeled linearly.

$$R(I) = \begin{cases} RMAX(I) & \text{if } ND < NO(I) \\ RMAX(I) \times \dfrac{(1 - ND + NO(I))}{NMAX(I) - NO(I)} & \text{if } NO \le ND \le NMAX \\ 0 & \text{if } ND > NMAX(I) \end{cases}$$

Actual reproduction rates are then determined from the R(I) by adjusting for winter food intake (YRFD(I)). This again models the birth rates RATE(I) as a linear function of food intake within certain bounds.

$$RATE(I) = \begin{cases} R(I) & \text{if } YRFD > INMAX \\ R(I) \times \dfrac{(1 - YRFD(I) + INMIN(I)}{INMAX(I) - INMIN(I)} & \text{if } INMIN \le YRFD \le INMAX \\ 0 & \text{if } YRFD < INMIN \end{cases}$$

The INMIN(I) and INMAX(I) parameters are the food intake levels beyond which birth rates fall to zero and attain the maximum respectively. They are age dependent.

These birth rates are then multiplied by the number of female deer of each age to determine actual fawn production each spring. Births are divided equally among males and females.

$$NDEER(1,J) = \tfrac{1}{2} \sum_{I=1}^{5} RATE(I) \times NDEER(I,1)$$

J = 1 (females), 2 (males)

I = doe's age.

Natural deer losses are taken during each time period according to the simple differential equation

$$\frac{d\ NDEER(I,J)}{dt} = -\ NATDR(I) \times NDEER(I,J)$$

where NATDR(I) is the natural mortality rate for deer of age I. Death rates do not vary during the year, and do not respond to changes in food availability, although a simple change in the model would allow this.

SYSTEM VARIABLES

State Variables

BIO(I)	Biomass of plant type I (1 = TREE, 2 = SHRUBS)
BIOFD(I)	Amount of deer food from plant type I
DELFD(I,J)	Food intake of plant type I by deer age J
ND	Total number of deer
NDEER(I,J)	Number of deer of age J and sex I (1 = female, 2 = male), J = 1, ... 5.
NHO	Hunting pressure (permit applications)--exogenous
NDVUL	Number of deer vulnerable to the hunt
RATE(I)	Reproductive rate for does of age I
TREE(I)	Population of trees of age I
YRFD(I)	Cumulative annual food intake for deer of age I. (Set to zero each fall)
V_u, V_s	Marginal values of the experience and kill, respectively

Control Variables

NH	Number of hunters
CLEARPC	Percentage of clearcut
NYEAR	Time interval in years between clearcuts
VUL(I,J)	Vulnerability level for deer of age J and sex I for hunting harvest. (0 = no harvest, 1 = full inclusion)
VDOE	Vulnerability level for all does.

PARAMETERS

A(I,J)	The degree of inhibition of growth of species I caused by the presence of species J
AFD,BFD	Deer food intake rate parameters
B(I)	Natural death rate for trees of age I
B_1	Hunting success parameter
C_o, C_1	Hunting experience valuation parameters
D(I)	Weighting factors to make food intake age specific
DD(I)	Die down rates for plant type I
DEL(I)	Food produced by tree of age I (per two-month period)
GAM(I)	Biomass of a tree of age I
INMIN(I)	Minimum food intake level, below which deer reproduction ceases
INMAX(I)	Maximum food intake rate, above which deer reproduction is unaffected by food intake
MC	Marginal cost of one day of hunting
NO(I)	Minimum deer herd density below which reproduction rates are unaffected by herd density
NMAX(I)	Maximum deer herd density above which reproduction ceases
NATDR(I)	Natural mortality rates for deer of age I
RMAX(I)	Maximum possible reproductive rate for deer of age I
S(I)	Deer food type preferences
VKILL	The value of a successful deer kill

PARAMETER VALUES USED IN SIMULATION EXPERIMENTS

A. Tree and Shrub Growth and Food Production:

I =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DEL(I)	.1	.5	.8	1.0	1.2	1.3	1.2	1.1	1.0	.9	.8	.7	.6	.5	.3	.2	.1	.1	.1	.1
GAM(I)	.1	.2	.4	.7	1.0	1.4	1.8	2.3	2.8	3.4	4.0	4.6	5.1	5.5	5.8	6.1	6.3	6.5	6.6	6.7
B(I)	.7	.8	.9	.9	.9	.9	.9	.95	.95	.95	.95	.95	.95	.95	.95	.95	.95	.95	.95	.95

A(1,1) = .0002 A(1,2) = .0000 A(2,1) = .0003 A(2,2) = .0001

P(1) = 25 P(2) = 2.5

DD(1) = .8 DD(2) = .9

B. Deer Feeding and Reproduction Parameters:

I = Deer Age	INMIN(I)	INMAX(I)	NO(I)	NMAX(I)	RMAX(I)	NATDR(I)	D(I)
1	8.4	12.0	20.0	200	0.1	.05	0.6
2	11.2	16.0	30.0	300	1.0	.04	0.8
3	12.6	18.0	40.0	400	1.9	.04	0.9
4	14.0	20.0	40.0	400	1.9	.06	1.0
5	14.0	20.0	40.0	400	1.5	.07	1.0

AFD = .02 BFD = .001 S(1) = .35 S(2) = .65

C. Hunting Model Parameters:

B1 = .001 M_C = \$25

	C_o	C_1	VKILL
MEAT	50	-10	500
EXPERIENCE	100	-20	100

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