62
80437

PLANNING IN THE DARK

Illuminating Natural Resources Development with a New Systems Process: the Rangelands and Wildlife Case

Stephen Berwick
Paul Faeth

September 1989

Draft edited by Seth Beckerman

CONTENTS

	Page
Acknowledgements	6
Forward	7
Chapter 1 AN INTEGRATED PLANNING TECHNOLOGY NOW	12
1.1 The Need for Integrated Planning	13
1.2 System Definitions	15
1.3 Historical Constraints in Systems Planning	17
1.4 Cultural Constraints in Systems Planning	20
1.5 An IPT Case from the Philippines	23
1.6 IPT Products	31
1.6.1 Managing Risk Reduction	31
1.6.2 Impact Assessment	34
1.6.3 Enfranchising Under-Appreciated Disciplines	36
1.6.4 Economic and Financial Consequences	36
1.6.5 Prioritization of Variables and Allocation of Resources	40
1.6.6 Project Monitoring and Evaluation	40
1.6.7 Education and Training	41
1.6.8 Environmental Data and Resource Assessments	42
1.7 Who Might Find IPT Useful?	46
1.7.1 Donor Agencies and Development Institutions	46
1.7.2 Research and Training Institutions	47
1.7.3 Resource Managers	48
1.7.4 Policymakers and Planners	49
1.7.5 Resource Users	50
Chapter 2 THE BASIS FOR DEVELOPING IPT	51
2.1 Immature Uses--Causes and Consequences	52
2.2 Use of IPT in New Problem Areas	53
2.3 Uses of Structure	55
2.4 Time--Using Systems to Analyze Dynamic Problems	58

2.5 Feedback and Control in Ecological Systems 61

2.6 Style: Differences in Planning as a Paradigm 66

2.7 Three Generations of Planning 72

2.7.1 First Generation - the Dominant Expert Monoculture 72
2.7.2 Second Generation - the Modular Multidisciplinary Team 72
2.7.3 The Next Generation: Interdisciplinary Planning for Integrated Systems 76

2.8 Models Featuring Structure, Time, and Feedback 78

2.8.1 Definitions and Uses 78
2.8.2 Different Uses of Different Models 82
2.8.3 Can We Trust Models? If Not, Can We Use Them? 86

Chapter 3 DEVELOPING AND USING AN INTEGRATED PLANNING TECHNOLOGY 92

3.1 IPT as an Analogue of the Scientific Method 93

3.1.2 Analogues of the Scientific Method in Planning 98

3.2 Users' Needs 103

3.3 The Workshop 109

3.3.1 Goals 109
3.3.2 Workshop Participants 113
3.3.3 The Protocol 114
3.3.4 Workshop Requirements: Facilitators and Logistics 123

3.4 Post-Workshop Computer Simulation 125

3.4.1 Model Development -- Flow Diagram 125
3.4.2 Data 129
3.4.3 Wooded Development--Encoding 139
3.4.4 Model Development--Compiling, Debugging, and Testing 144
3.4.5 Sensitivity Analysis 148
3.4.6 Model Development--Requirements 149

Chapter 4 RANGE, LIVESTOCK, AND WILDLIFE -- AN INITIAL FOCUS FOR IPT 151

4.1 Focusing on Range, Livestock, and Wildlife 152

4.2 Range Ecology and Management 154

4.2.1 Definition 154
4.2.2 Ecology 156
4.2.3 Management 167

4.3 Population--the Most Significant Ecological Factor 169

4.4 Review of Range Development Approaches 171

4.5 Problems Resulting From Development Attempts 173

4.6 Toward Sustainable Rangeland Uses - Game Ranching & IPT 179

4.6.1 Social and Economic Considerations Favoring Wildlife 180
4.6.2 Ecological Considerations Favoring Wildlife 185

4.7 Status of Game Ranching 196

4.7.1 Meat Production--Cattle and Wildlife 196
4.7.2 Safari Hunts 200

4.8 Summarizing--a Rational Transition 202

Chapter 5 USING IPT FOR PLANNING AND MANAGING RANGE, LIVESTOCK, AND WILDLIFE RESOURCES 205

5.1 Introduction 206

5.2 Understanding Goals, Problems, and Questions: the Workshop Results 207

5.2.1 Macro Level Workshops 207
5.2.2 Local Level Workshop 211

5.3 Schematic Model of a Range, Livestock, & Wildlife System 222

5.3.1 Overview 222
5.3.2 Range Submodel 222
5.3.3 Livestock Submodel 237
5.3.4 Wildlife Submodel 250
5.3.5 Ranch Accounting 264

Chapter 6 VALIDATION, POLICY TESTING, & SENSITIVITY ANALYSIS 267

6.1 Introduction 268

6.2 Validating the Range, Livestock, and Wildlife Model 269

6.2.1 Structure and Testing at Extremes 270
6.2.2 Model Calibration and Validation 272

6.3 Model Behavior 285

6.4 Testing Management Options for Livestock Operations 293

6.5 Parametrical Sensitivity Analysis 310

6.6 Conclusion 322

References 324

Additional Reading 331

ACKNOWLEDGEMENTS

The users of the technology we describe have helped to build it and have guided its evolution at many workshops over the past five years. The authors are largely their scribes and voice. We acknowledge the support of the ranchers and other resource managers at Chiredzi, Zimbabwe, particularly our hosts there, Roger Whitall, Mark Sparrow, Clive Styles, and Clive Stockhil. Brian Childs' contribution of data and insight was also much appreciated.

Of the many people at USAID who were there when we needed them (often), Dr. John D. (Jack) Sullivan provided enthusiasm and guidance as well as material support in the Science and Technology Bureau. Dr. Robert Ichord first saw and defined the need for an IPT and provided the initial environment for its growth in the Asia Bureau.

Finally, the vision, patience, and support of David Runnalls, then directing the North American office of the International Institute for Environment and Development, made this effort possible. The World Resources Institute has graciously assumed the burdens of final preparation of the manuscript.

We hope that the products of IPT, such as this volume, will have warranted the support of the many friends and colleagues, acknowledged and anonymous, who have been so helpful.

FORWARD

The Recent Evolution of Integrated Planning Methods

In 1983, the U.S. Agency for International Development (AID) reviewed requests for technical assistance that it had received from its missions. An analysis of the requests submitted through AID's Environmental Planning and Management (EPM) Project showed a need to integrate the project planning efforts by AID staff with different interests and expertise. The EPM environmental technology transfer project had received over 70 requests, and 22 percent involved integrated system issues. There was a strong consensus to use holistic approaches to accommodate the complexity which is characteristic of Agency work in the environmental aspects of economic development. The desire to have integrated approaches and tools was repeatedly expressed at a series of USAID meetings during the winter of 1983. It was also clear that no tools accessible to AID staff at that time satisfied their need for methods to objectively integrate activities at all stages of their projects--planning, research, implementation, and evaluation.

The response to this analysis was the development of Integrated Planning Technology (IPT). The IPT project which developed the planning tool reported here, was a cooperative agreement between the World Resources Institute (WRI) and AID. A cooperative agreement differs from typical consulting contracts in that AID uses the completed work to improve the policy, planning, and implementation capabilities of the Agency. This

policy dimension of cooperative agreements is one way the Agency educates itself through an iterative dialogue with its friends and critics, while the contractor improves its capabilities in these areas. This is considerably different than most consulting jobs, where the contractor moves on to other work at the completion of the contract.

In the spirit of such a cooperative agreement, IPT was designed to find a better, more economical way to address policies, programs, and projects by better understanding goals, issues, and information requirements, and by testing alternative policies. EPM projects treating land-use conflicts near a national park in Nepal, a dam and irrigation project in the Philippines, coastal resource management in ASEAN nations, and the integration of discrete, resource-specific chapters in a National Conservation Strategy for Botswana all contributed to our perceptions of where an integrated planning tool could be helpful, and the form such a tool could take. These were the AID-to-EPM elements of the cooperative agreement. This book is one of the returns to AID. It assists Agency efforts in planning which can be enhanced and sustained beyond the completion of individual projects.

The first co-author and the Energy/Environment Director for AID's Asia Bureau (as the Agency was then constituted) began development of what has become Integrated Planning Technology (IPT) in 1983. The first trial (in 1984) attempted to use many

of the methods described here to plan, after the fact, the USAID portion of the Mahaweli River Basin Development Program in Sri Lanka. The Mahaweli was a project which had been planned and replanned by the government and at least seven donors for some twenty-five years. We hypothesized that a new, integrated method could offer some measurable improvements and provide a better record of planning than had been the case. For example, it incorporated forestry and wildlife in the assessment of environmental impacts and project costs and benefits. We marveled that foresters had not been a part of planning for the Mahaweli project for twenty years. Although larger than many international development projects, the Mahaweli served well as an example of discipline-specific, modular, and reductionist planning.

After the 1984 Mahaweli workshop, subsequent development of IPT was led by the Office of Forestry, Environment, and Natural Resources of the Bureau for Science and Technology, USAID (S&T/FENR). S&T is responsible for the development and dissemination of scientific and technological information, analyses, and tools required by the Agency. S&T/FENR originally charged the authors with employing IPT to develop a prioritized research agenda, based upon workshop-derived models of their primary existing areas of activity and interest: forestry, coastal resources, range, and wildlife management.

In March 1986, an Agency-wide workshop addressed these resource sectors and several others which are closely linked. Flow diagrams of conceptual models representing nine sectors were produced. These included agriculture, socioeconomics, population/health, watershed/soils/hydrology, as well as the resource program areas of S&T/FENR. Ultimately, many of the demographic, economic, agricultural, and other structures were incorporated in the models of focus for FENR: forestry, coastal resources, range, livestock, and wildlife management. Twelve AID offices, as well as several experts representing contractors and other agencies such as the Department of Agriculture, participated in describing the goals most often expressed and the problems and systems most often encountered on AID projects in these sectors. Scientists were then hired to locate, interpret, and report the data for the identified parameters. The participants developed flow diagrams to represent the resource system structures they defined and which reflected their considerable experience.

Since the effort to develop IPT began and the products of the Mahaweli Bioresource Systems Workshop were produced in 1985, hundreds of participants at seminars and workshops around the world have contributed to the latest version of IPT described in the book. This has been a peculiarly public and interactive process.

In 1987, a mid-term evaluation of the IPT project determined that further work to produce a prioritized research agenda should await a careful validation of one important sector. IPT needed a "reality check." Because of the training and field experience of the IPT staff, the Range, Livestock, and Wildlife model was selected for validation, and data on tropical semi-arid rangelands were collected for East and southern Africa. In early 1988, the staff visited Zimbabwe and Kenya to contact managers, administrators, and operators, revise original data in files, inspect the sites, hold workshops to involve the users, and build the model structure. These visits provided much of the information required to validate the model, which is reported in Chapters 5 and 6.

Chapter 1

AN INTEGRATED PLANNING TECHNOLOGY NOW

		Page
1.1	The Need for Integrated Planning	13
1.2	Definitions	15
1.3	Historical Constraints in Systems Planning	17
1.4	Cultural Constraints in Systems Planning	20
1.5	An IPT Case from the Philippines	23
1.6	IPT Products	31
1.6.1	Managing Risk Reduction	31
1.6.2	Impact Assessment	34
1.6.3	Enfranchising Under-Appreciated Disciplines	36
1.6.4	Economic and Financial Consequences	36
1.6.5	Prioritization of Variables and Allocation of Resources	40
1.6.6	Project Monitoring and Evaluation	40
1.6.7	Education and Training	41
1.6.8	Environmental Data and Resource Assessments	42
1.7	Who Might Find IPT Useful?	46
1.7.1	Donor Agencies and Development Institutions	46
1.7.2	Research and Training Institutions	47
1.7.3	Resource Managers	48
1.7.4	Policymakers and Planners	49
1.7.5	Resource Users	50

1.1 The Need for Integrated Planning

Many of the horror stories in development assistance are attributed to the consequences of modular or open-system planning. The cause and effect logic used in this type of planning is occasionally useful to solve engineering problems, but such approaches do not reflect the feedback controls so common in biological, social, and economic closed systems. This lack of integration and feedback were themes in an early collection of development gone awry (Farvar and Milton, 1969), but unfortunately, since the publication of the book Careless Technology, the list of examples has grown. The Aswan Dam and its effects in Egypt were described in their book. Other examples include:

- In Indonesia, agricultural lending policies encouraged farmers to buy the high-yielding rice of the Green Revolution, but the loss of varietal diversity and the resulting devastation by pests severely affected many small farmers who were part of the program.

- The Livestock II project in Botswana fell far short of its objectives. Instead of fostering rangeland conservation with a "stewardship through ownership" approach to rangeland allocation of the grazing commons, the vested interests did exceedingly well, traditional social structures dissolved, and neither the intended economic nor environmental projections were measurably achieved. Yet this project is a starting point to plan a similar intervention -- Livestock III.

- Migration of people from crowded areas in Indonesia to less populated islands did not enhance their quality of life to the degree planned. Three tenets of successful rural development were violated: poor (or no) advance characterization of the site to be developed with knowledge of the migrants' capabilities; inadequate determination and provision of appropriate approaches and technology; and no

long-term support beyond the usual horizons of development and project plans (Richards, pers. comm.).

Without delving into the details and controversies surrounding the numerous development disappointments, these projects lacked the planning approach implied by IPT. Recently several new technical developments have evolved which make an IPT now possible.

- Ecosystem approaches, analyses, and methodology has revealed some resource system connections (Van Dyne, 1969; Orians, 1986).
- General system concepts such as control engineering (system self-regulation), cybernetics (the nature and role of information), and organization theory (structure and decision-making) have matured to application.
- Computational capacity (microcomputers and simulation modeling software) has made the necessary computational power easy to use and available to many planners and technicians on an interactive basis.

1.2 System Definitions

In describing flaws in historic approaches to developing renewable resource systems, we have used some terms which need definition. A system can be considered a bounded collection of interacting elements which function together for some common purpose (Roberts et al., 1983). A lawn mower engine is not a system by this definition, but a lawn mower, lawn, and operator is a system. A model is a simplified representation of the system which lets us test our beliefs about the system and enables us to make decisions about its management. For example, we probably do not need information about soil fauna to decide to mow the lawn. A simulation is a projection of the behavior of the system as expressed by changes in the elements (variables) in response to goals and a management decision, for example, whether to mow the lawn once a day or once a month. These projections change over time depending on the changing values of the variables. The projections describe the behavior of the variables of interest, such as the plant biomass.

In fact, we employ mental models of systems to make most of our daily decisions, such as when we decide to cash a check, play a game, or make an investment. We are all habitual modelers, and those who are more skilled at setting boundaries of a system, identifying the right elements, remembering important facts about the elements (data), or past history of their actions and system

responses (validation), win. They "win" because they are better informed modelers -- better planners and problem solvers.

The use of more formal approaches to systems analysis for testing policies becomes advisable as the elements and relationships increase to the point where:

- there is too much information to keep track of to make a sound decision, and
- management costs and consequences increase. It is advisable to test airplane designs in a wind tunnel before construction, or to give new pilots time on a flight simulator before they take us up. The same care is warranted for the design of a development project affecting the well-being of people.

The over-focused planning of the previous generation ignored such common and critical system determinants as change over time, intra-system linkages, and feedback controls. IPT was conceived as an attempt to integrate many elements and fields of knowledge with the consequences of management costs to achieve more informed, efficient planning.

1.3 Historical Constraints in Systems Planning

IPT was developed on the premise that satisfactory tools for applying systems analysis during planning had never materialized because none of the many approaches were specifically tailored for the development pragmatist. These people may possess a legitimate and healthy skepticism about:

- estimates for missing or suspect data;
- computer-oriented specialists who have not researched and managed the systems in the field which they have characterized from the office (an academic approach, the "black box");
- a computer-oriented planning technology which is not understood (analogous to the suspension of belief experienced at a magic show);
- past modeling exercises which produced trivial or erroneous analyses; and
- any technology which produces quantitative information about the future. If modelers possess such powers, why aren't they at the race track?

The main issue is confidence and credibility in what is partially a predicative tool.

The principal means by which IPT addresses these important issues is to have the user/planner build the model. By using a well-defined analytic process, the users generate a model which addresses the correct issues and system. The issues and system are defined in an interdisciplinary workshop assisted by IPT staff, who will further elaborate, and if appropriate, encode the system which is developed. The user can provide the units of

measure for the data and even some of the data points required by the model. The user helps build the system representation (model) and should therefore understand it. The quality of data used for the model's parameters is assessed, and data are entered on a large, accessible database. This stored information now exists for many elements of the systems (variables) which have been identified (See Chapter 3, Section 3.4). IPT workshops can affect the objectives, variables, and system construction by faithfully adhering to the workshop protocol described in Chapter Three. One of the evolutionary trends in the IPT process has been the immediate encoding of portions of the suggested model with the users present. This process demystifies the procedure and generates a feel for cause and effect between model structure, analysis, and output.

Despite the involvement of those who will use IPT in depicting the system to be developed, the issue of credibility can never be completely resolved because the projection of future behavior can never be proven in the present, at least not in the way a statistical test can identify the level of confidence in observable phenomena. However, we can feel reasonably confident about using a model's simulation of the future if:

- the structure is credible in the experience of those who construct and use it, and in the opinion of scientists who should know details of system pattern and process;
- the structure is consistently rebuilt by other users at other workshops without prior knowledge of the previous depiction;
- assumptions and poor data are minimized;

- the model is validated by using a data set collected for a similar system over a long period to test its accuracy ("predicting history"); and

- the entire process -- workshop, protocol sequence, encoding, testing, data collection, and policy testing -- is at least as logical, efficient, and useful as other existing ways of planning which it would augment, but not necessarily replace.

The authors, who are typical applied science users, do not view IPT as an end in itself, but rather a means. IPT is one of several useful tools in the research/management/planning tool kit.

1.4 Cultural Constraints in Systems Planning

System dynamics and its tailored computer simulation languages Dynamo (for IBM) and STELLA (for Macintosh), have been applied to the management of industrial dynamics and engineering systems since their development in the 1950's. System dynamics (which is described in Chapter 3, Section 3.4), is an analytic approach developed at the Massachusetts Institute of Technology which is used to manage integrated systems (Forrester, 1969). Dynamo is a computer language particularly suited to system dynamics. It was originally used on main frame computers, but the latest versions are written for microcomputers.

Forrester and his many students, like many developers of mathematical models, were unified by a culturally consistent approach to problem solving, which is reflected in its filial product, IPT. These early users often modeled elements of human behavior central to many developments or industrial improvement. The approach is generally dominated by rational, logical methods, a managerial rather than a passive or fatalistic view, the use of computers, and the assumption that human action can be predictable and thus managed, at least in the aggregate. Meadows (1980) quotes Schumacher (1973, page 213): "In principle, everything which is immune to the intrusion of human freedom, like the movement of the stars, is predictable. Does that mean that all human actions are unpredictable? No, because most people, most of the time, make no use of their freedom and act

mechanically. Experience shows that when we are dealing with large numbers of people, many aspects of their behavior are, indeed predictable -- only a tiny minority are using their power of freedom, and they often do not significantly affect the total outcome."

Schools emphasizing engineering and economics have produced some brilliant and widely employed research and planning models. However, the challenges of planning for the poorly understood biological systems and cultures outside western logic confound our rational approaches to "averaged" people. Furthermore, in spite of Schumacher's hyperbole, not everything immune to human intrusion (such as a typhoon or earthquake) is currently predictable. Such events can be much more significant to the less buffered human communities in the developing world, and require different visions of need, cause, effect, and success or resolution. Cultural or religious diversity, fatalism, and other unfamiliar (to foreign observers) behavioral drivers can confound the logical managerial modeler seeking to understand an unfamiliar development environment. This presents a challenge to planners using such standard planning techniques as mental models.

One move toward a solution is to devise a structure for translating and compiling an unfamiliar world view into a format which will inform the planners. The IPT workshop described in Chapter 3 was designed not only to elicit the views of the hosts

and presumed beneficiaries of our technology, but also to serve as an effective vertical communication technique for all the strata affected by a development, from peasant to administrator. These strata are also often different within a host country -- in language, material culture, world view, vocational pursuits, etc. This local diversity can pose the same problem for planning and modeling as the western vs. endemic dichotomy.

Furthermore, complex biological systems, like behavioral systems, are less tractable than physical systems which may yield to engineering solutions. Relatively recent efforts in systems ecology attempt to clarify ecosystem function and management. The use of simulation modeling by ecologists and the genesis of IPT are natural milestones in the evolution of systems science and system dynamics. As ecology continues to benefit from mathematical modeling techniques developed for other disciplines, such as engineering, and as methods emerge from constraints imposed by a western tradition addressing non-western people and issues, development assistance can begin to make good use of this new approach.

1.5 An IPT Case from the Philippines

Although IPT has been in a development phase leading to the publication of this report, several applications at workshops have indicated the benefits IPT may provide.

Very few international development projects are easy. Certainly one of the most difficult planning environments now challenges the new government of Negros Occidental, an island province in the central Philippines. Negros was originally characterized by humid tropical forests and seagrass-mangrove-reef environments. The elimination of the American sugar import quota, new substitutes for sugar, and corruption, coincided during several weeks in 1986 to cause a dramatic collapse of the economic backbone of the province, sugar growing and processing. Nearly all sugar workers and their families housed in the sugar haciendas were already suffering clinical evidence of malnutrition when virtually all sugar workers were fired. Starvation and recruitment to a national insurrection became a reality. The new governor attempted to redress the interrelated problems of the bankruptcy of plantation owners, worker poverty, growing guerrilla and reactionary armies, tenure inequalities, and environmental deterioration. His land-use plan proposed forgiving a fraction of the plantation owners' mortgage in trade for 10 percent of their land to be given to the peasant workers for subsistence agriculture. He would diversify the disastrously

vulnerable sugar monocrop on 30 percent of the land, and the remaining 60 percent would continue to grow sugar to satisfy domestic markets and keep the processing facilities alive.

In the fall of 1986, we were invited to evaluate the governor's plan and employ IPT to suggest alternatives. A workshop with enthusiastic local planners generated useful evaluations which had not as yet been factored into planning. Perhaps the most provocative products emerged from examining the simulated behavior of the Negros Occidental system. Model runs indicated that the governor's **diversification** policy would not produce the anticipated benefits above a **base case** or "do nothing" scenario for some of the important goal behaviors tested (See Figures 1-1 to 1-4). A goal behavior is the behavior over time of an important element (goal variable) in a system. Such change responds to a particular policy. It is essential to know the response of variables in order to assess the value of the policy. As examples, two natural resource indicators (forests and mangroves) and two socioeconomic indicators (food and economic benefits) were examined.

To explore a possible land-use strategy which the governor's planners had not yet considered, we evaluated the comparative benefits of a regeneration program to reclaim the large area degraded because of past land abuse. The allocation of transitional financial support for 5,000 families a year to spend three years transforming the noxious *Imperata* grass (cogon or

alang-alang) to food crops was costed, and the costs and benefits displayed in the net present value analysis.

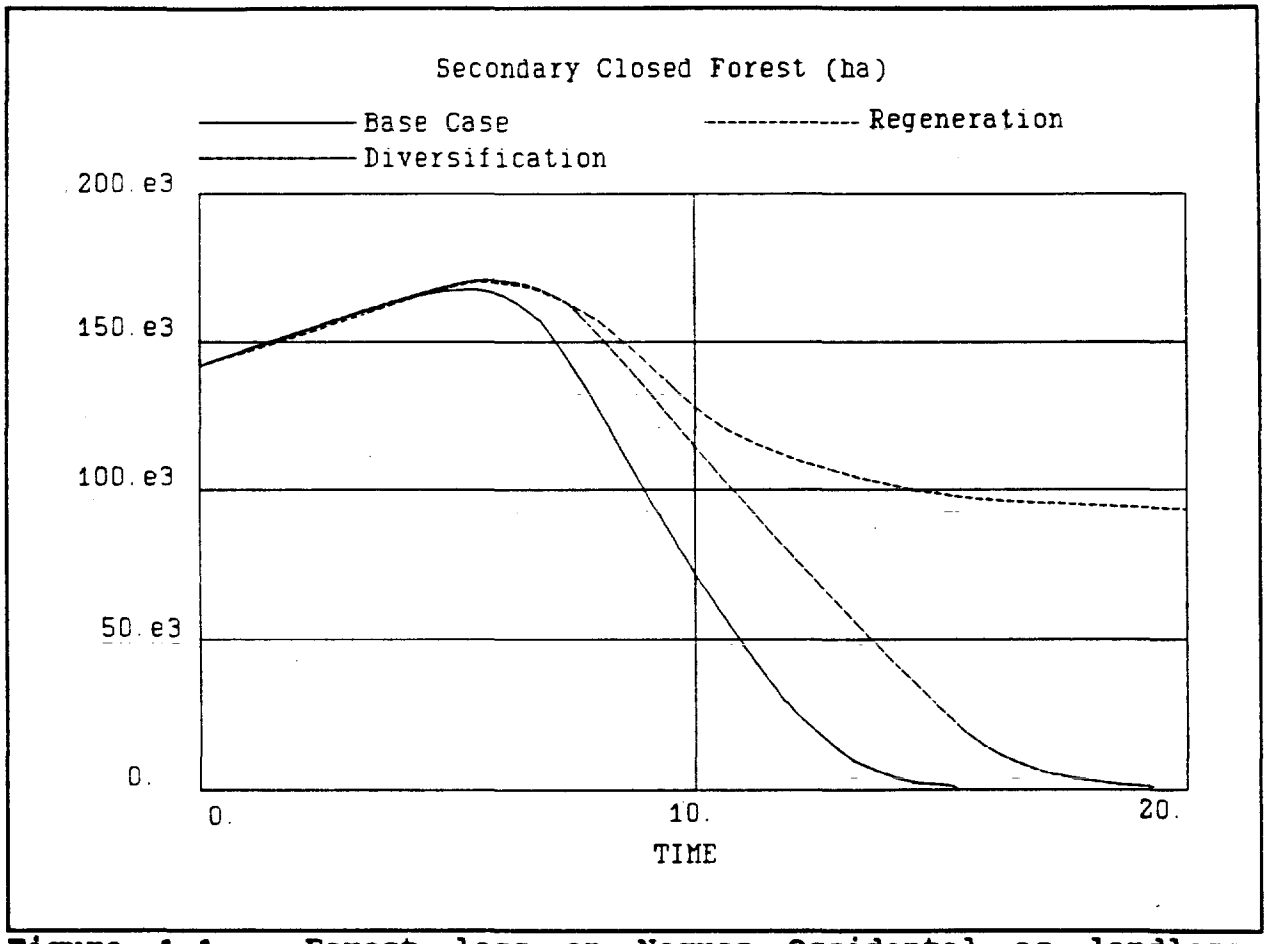


Figure 1-1. Forest loss on Negros Occidental as landless, unemployed sugar workers resort to slash and burn subsistence farming on erosive slopes with short crop rotation. (Simulated results.)

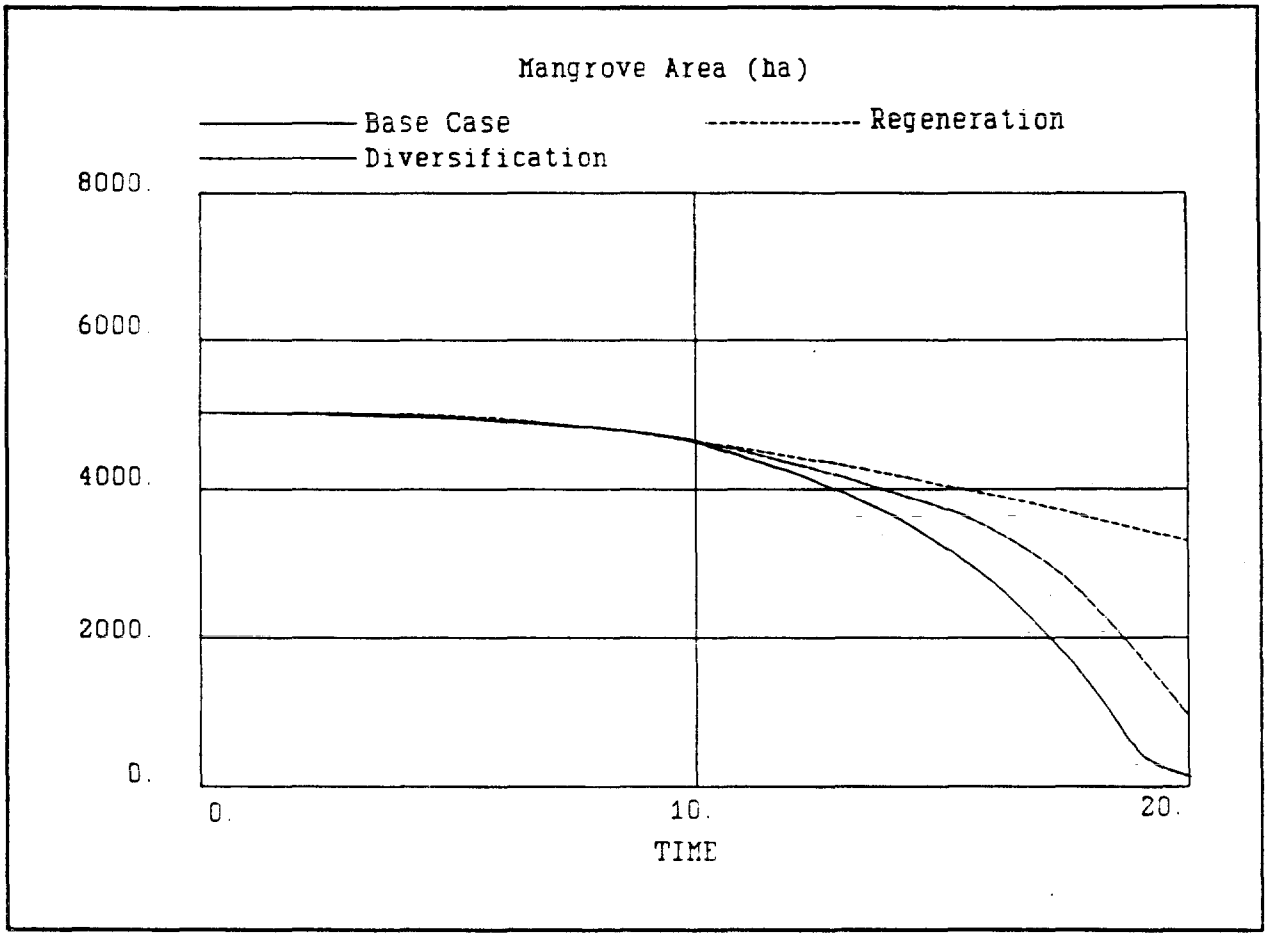


Figure 1-2. Land tenure effects on mangrove mortality due to prop root suffocation from sedimentation. Reclamation deflects slash and burn forest conversion, and reduces sediments relative to other land uses tested. (Simulated results.)

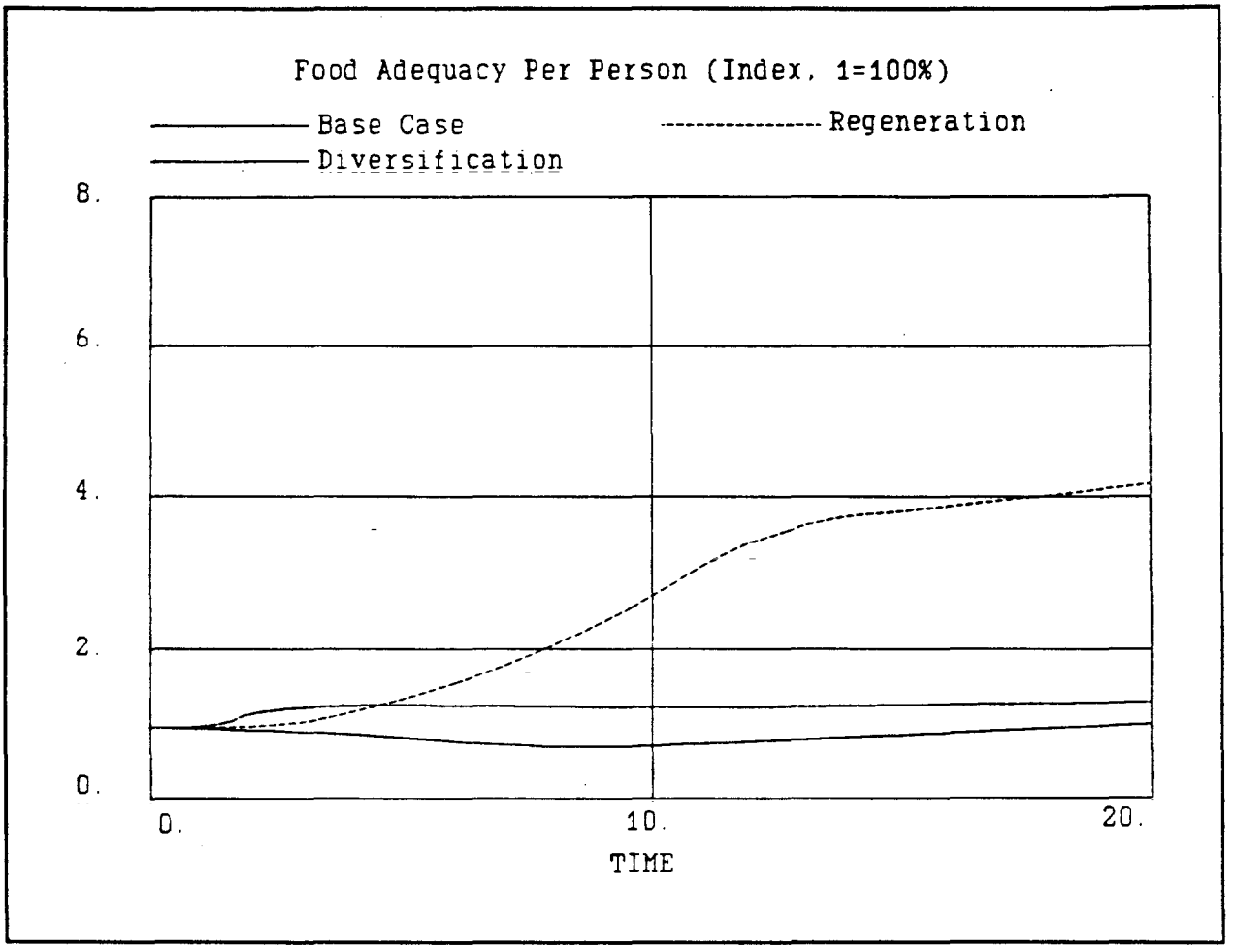


Figure 1-3. Food adequacy relative to 1,850 calories per day. Index (1.0 = 100 percent) illustrates a shortfall in the base case with the governor's 10:30:60 plan, and a four-fold saleable surplus with a regeneration scenario. (Simulated results.)

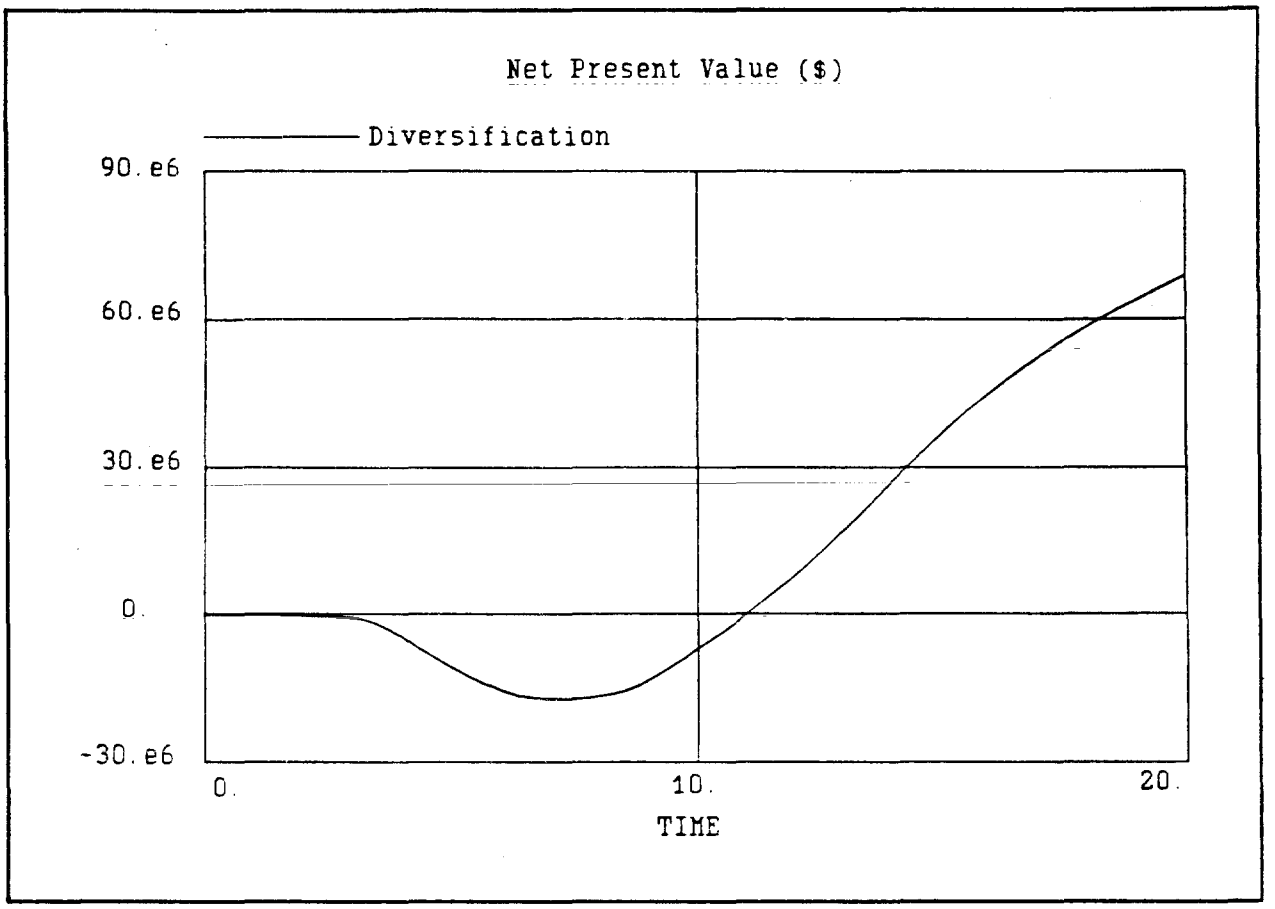


Figure 1-4. Return on the investment in a regeneration scheme compared to investing the money at 10 percent interest elsewhere. The project begins at year three, breaks even in less than ten years, and shows a substantial economic return by twenty years. The assumptions are conservative. (Simulated results.)

Secondary Closed Forest Land. If the economic refugees from the haciendas were forced to the forest to practice subsistence slash and burn agriculture without any regeneration, the forest may be decimated. By reducing the pressure from shifting agriculture with the reclamation scenario, it may be possible to preserve about two thirds of the pre-crash forest area (See Figure 1-1).

Mangroves. Land use changes in the watershed can affect this resource through erosion and sedimentation. If the mangrove prop roots are covered with silt, the trees soon suffocate. Increases in such land uses as shifting agriculture, forest fallow, and unproductive land lead to substantial erosion and sedimentation of the mangroves, with the subsequent loss of mangrove-dependent fisheries. Two thirds of the protein for human consumption on Negros Island comes from fish, and about 85 percent of these species depend on the mangroves during some part of their life cycle. The preservation of forest land and the reclamation of unproductive land have a much more benign effect on this important resource (See Figure 1-2).

Human Nutrition. An index of food adequacy demonstrates the implications of the three policies. In the base case, unemployment and the inability of the people to make up a food deficit through shifting agriculture leave them without enough food. In the diversification scheme, the 10 percent of the land allocated to subsistence agriculture is enough to produce a small surplus, but in the regeneration scheme, rehabilitation of unproductive land allows an almost four-fold surplus (See Figure 1-3).

Net Present Value. Using the World Bank's minimum criteria for discount rates (10 percent), the regeneration scheme may be financially as well as environmentally sound (See Figure 1-4).

Although the accuracy of the numeric output had yet to be tested, the planners were challenged to rethink existing dogma and plans. For example, neither the potential effects of upland uses on vital coastal resources, nor the costs associated with ignoring these links during planning had been considered earlier. The planners welcomed IPT as an organizing concept and process. Although they had considerable anecdotal knowledge and a feel for local processes, planning tools did not exist to help structure and efficiently use their insights.

The model was not left with the planners on Negros Island because the abbreviated workshop and data collection effort could result in possible misuse of the results and the process. Furthermore, IPT had not yet been validated as a process which could generate reasonable confidence in the future behavior of variables. Although the logic of the process was clear, the credibility of the products had not been established through validation, and care had to be exercised to avoid overselling a yet-to-be tested tool.

1.6 IPT Products

1.6.1 Managing Risk

Reducing uncertainty in some high-risk activities and environments is a goal of most planning and some IPT products. In fact, the reduction of risk subsumes impact assessment, planning, monitoring, and training, and is both an IPT product and a dominant goal. Reasons for uncertainty in the development of natural resources include:

- Changes in social preferences, policies, and goals. In the United States, public perceptions and environmental regulation experienced great changes between 1960 and 1970, and priorities reflecting these attitudes also changed. Government programs, which are expressions of ideologies, changed elsewhere as well -- as, for example, in Indonesia in 1965, and in Zimbabwe in 1980.
- Poor data, which makes policy analysis difficult. The knowledge to judge between alternative policies is necessary.
- Imperfect or erroneous knowledge of structure and function.
- Unpredictable conditions such as catastrophes which can arise and confound a plan.

A planner's goal is to cope with uncertainty and to minimize surprises. Response to surprises tends to be reactive, and the likelihood of an inappropriate response increases. Humans and their institutions have generally attempted to reduce uncertainty through trial and error. Holling (1978) identifies three types of uncertainty:

Stochastic Events. Existing analytic tools can help plan for these random events (e.g. typhoons and droughts). Their

occurrence can be estimated by statistical procedures (e.g., Monte Carlo simulations).

No Empirical Record. Imaginable and partly describable possible occurrences make this class difficult to understand. There is no prior knowledge of outcomes or probabilities of occurrence. Once such events do occur, they can move to the first category. A nuclear plant or weapons system failure can be in this category.

Unimaginable Events. These events are without precedent and have unknown processes, such as AIDS for the world of fifty years ago.

Uncertainty is part of our condition. Since it can not be wished away by those who engage in the uniquely human activity of planning for the future, our institutions are attempting to cope with uncertainty by trading off two basic strategies: preventing failure or surviving failure (Holling, 1978).

An activity to support the strategy of preventing failure might be the collection of the best data possible to form decisions. The strategy of surviving failure would be supported by the judicious use of trial and error (sticking your toe in the water). We can never completely replace experience, because we can never hope to eliminate uncertainty. Given the importance of this strategy, it is useful to summarize Holling's (1978) minimum conditions for the employment of trial and error:

- it cannot destroy the experimenter;
- the experimenter must be able to analyze and learn from the errors;

- the trial cannot completely change or destroy the environment (or the lessons learned will not be of use); and
- the experimenter must be willing to try again.

The agent in these experiments must be something of a risk-taker and entrepreneur. Memory, analytical, and problem-solving ability and a taste for adventure are characteristic. Memories can be transcribed as history in books or fables, and experience can be socialized or ritualized for all generations. Military historians will certify that battles rarely go as planned. Even with the best data, uncertainties creep in, and, ultimately, experience is a useful ally. Eliminating uncertainty is rarely possible and, therefore, successful planning requires the use of experience, worst-case assumptions, and quantitative forecasting and policy testing.

IPT is a technique which bridges the decision to emphasize either planning or trial and error. It can capture the varied experience of many risk-takers while using a technique of forecasting and data collection favored by planners. It requires prior information to develop good policies, but tests alternative policies using models before a massive commitment is made. IPT's primary contribution to development planning is the capability it offers to the trial and error process before there is any massive commitment to implementing a project. Policies are tested and dissected before they are implemented. IPT can identify unexpected relationships and behaviors for further inspection by

techniques such as risk analysis. As long as the model is good and the planners discover some errors and learn from them, the model is contributing toward planning the project and future actions.

1.6.2 Impact Assessment

A major product of an IPT simulation is the identification and analysis of environmental impacts which may result from project-related environmental changes. Ideally, it is used proactively. An environmental assessment, as a disclosure document, is required to predict project effects on measurable attributes of the system being developed, assess their impacts, and the significance of these impacts (Berwick and Soewardi, 1991). The cumulative effects of numerous project actions over time, mitigation, and alternative project configurations are also generally required in an assessment.

Multidisciplinary teams have not often generated a realistic view of either the baseline or the future because of their modular, reductionist approach. Except for informal communications, the lack of an integrated systems approach precludes timely transfer of information addressing specific links between disciplines. Scientists labor in relative isolation while producing their chapters on each important resource. These chapters may be delivered under one cover, but they are separated by the process.

IPT workshops inform each participant of the specific requirements (variables, rates, information) of the other disciplines. Such an integrated view should be developed early enough in the process to influence the selection of resources and attributes to be measured, scheduling of products, data priorities and exchanges, and other parts of the environmental impact process.

IPT has an unusual role to play in the element of the environmental impact assessment process known as scoping. Scoping is the public and external agency review and comment process designed to identify and accommodate public, national, or international concerns and suggestions at the early design and siting phase of a project. At minimum, early and tentative design alternatives must be tendered for public review in an open hearing. In theory, early consultation will educate both the affected public and project proponent, materially assist project planning, and co-opt possible future opposition to the project. IPT could provide a structure for scoping sessions which have tended toward unfocused personal statements. The process generates an orderly, focused public expression. Because of early and structured public participation, the eventual project would be more explicable to the typically diverse lay public. This is important because it helps to address a consistent flaw in the environmental assessment process -- the inability of the general public to understand the often quite technical

feasibility study and draft assessment upon which they are later asked to comment.

1.6.3 Enfranchising Under-Appreciated Disciplines

Because the IPT process identifies the need to incorporate specific variables related to resource sectors and disciplines such as forestry, economics, or wildlife, contributions to the system and specific links to other sectors are explicit. The important contributions of politically or historically weak disciplines such as range or wildlife will be clear. The agricultural engineer will know how much information or productivity will be lost if the wildlife ecologist is not consulted.

1.6.4 Economic and Financial Consequences

International development assistance operates in a difficult fiscal and bureaucratic environment. For example, large projects, intractable environments, catastrophes, politics, and new Mission or project staff will frequently generate change-orders and the need for rapid replanning and costing. Most staff would enjoy a participatory planning technique such as IPT, which rapidly produces quantitative, objective analyses in months rather than years (two years is an average gestation period for a USAID project paper). The project will also be evaluated during its life, and the staff will need to justify planning rationale and finances. In other words, more tools to promote objective

outputs and enhance planning efficiency are required in an environment with rapid planning requirements.

The financial implications of a development policy are also evaluated in IPT models. Of obvious concern to the individual rancher as well as to a large donor are the costs and benefits of a development policy relative to plausible alternative policies. The Range, Livestock, and Wildlife model described in this report produces a financial analysis for the rancher. IPT generates a net present value estimator using the discount rate assumptions employed by the World Bank, however it brings two uncommon features to such analyses.

First, IPT functionally integrates the several hundred elements and processes which the workshop experts have determined define the system. This should presumably account for often ignored contributions of a variety of interacting resources, as well as some of the costs of their depletion. For example, overgrazing seems to interact with drought in ways that reduce cattle productivity, even during later post-drought periods of normal rainfall. This reduction in productivity is accounted for in annual ranch income statements in the model (See Chapters 5 and 6, Sections 5.3, 6.3).

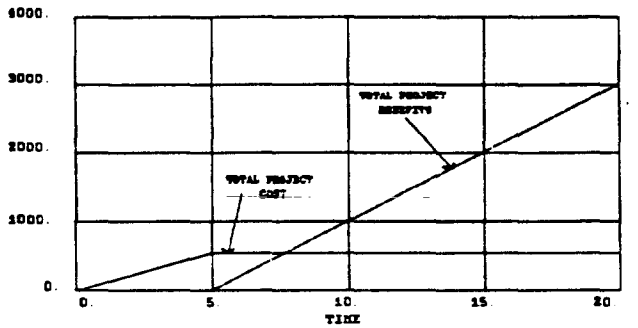
The value of profits discounted at a 10 percent compound interest rate (what the money would earn in a bank over the life of the project instead of being used in the project or ranch investment) is computed. This calculation shows whether the

project investment will be profitable, and when it will break even (when the initial outlays are paid back including interest which would have been earned). Again, changes in all the interacting elements and resources of the system are accounted for, not just the fifteen or twenty isolated (i.e., not interactive) inputs and outputs usually used in a project's benefit-cost analysis.

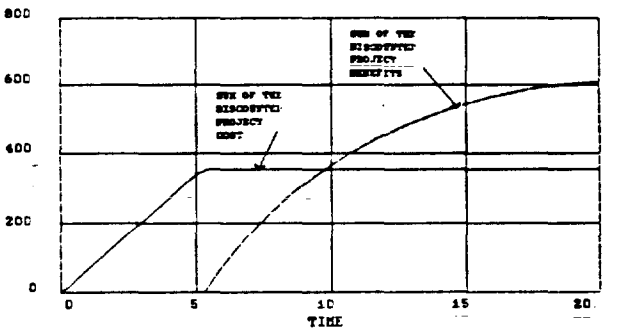
The second uncommon feature of the IPT net present value (NPV) analysis is that it is dynamic and displayed throughout the life of the project, showing its behavior in a way that can be compared with the NPVs of alternative policies (See Figure 1-5). Most NPV analyses do not project cost-benefit performance annually, but at the beginning, break-even point, and end of a project. Analysis can also be done to determine the internal rate of return, which is the interest rate the investment would earn if put in a bank.

x-axis: US$ **y-axis:** Time (years)

The total costs would look like:



The sum of the discounted costs and returns would look like:



Subtracting those two curves yields the Net Present Value for the project:

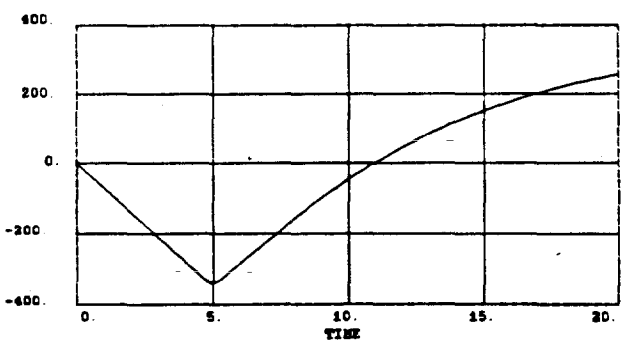


Figure 1-5. Net present value of a project over its life. a. Total costs. b. Sum of the discounted costs and returns. c. Net present value of the project (difference between the two curves in b).

1.6.5 Prioritization of Variables and Allocation of Resources

A process of analyzing each variables' contribution to the behavior of the system is known as "Sensitivity Analysis" and is described in the Appendix. Those variables or feedback processes which are major contributors to system behavior are candidates for later data collection, research, or monitoring efforts.

1.6.6 Project Monitoring and Evaluation

When a system has been characterized and a simulation model used to address the project goals and key questions, departures from the anticipated behavior of goal variables can be analyzed by comparing actual monitored data with model projections, and inspecting model structure and linkages. This process may reveal the causes of problems and suggest corrections. This process extends the values of the original analysis in time and can produce new projections employing new data and partial validations. The effort of project staff and supporters (e.g., donors) to adapt and refine the efforts in progress, fosters continued interest and obligation. The financial implications of mid-term adjustments can also be evaluated. IPT facilitates such evaluations by providing an objective process and a record of original planning assumptions through the products of the original IPT workshop, for example, goals, issues, and in particular, the flow diagram with a supporting data base.

1.6.7 Education and Training

One of the reasons IPT was developed is because there are so few planning tools available for an integrated approach, but the utility of a systems approach is not universally appreciated. Although IPT workshops around the world have involved hundreds of participants, by no means is there universal appreciation of the need to work with experts outside of one's discipline. The advantages of doing so are not always clear. Another common characteristic of project planners and participants, particularly in some of the more isolated areas, is a near total lack of formal knowledge about the resources to be developed or conserved. There is not much chance that years of formal training in such applied sciences as forestry and wildlife ecology, or in fields such as policy analysis and economics will occur in time to assist planning or implementation, yet an appreciation of resource pattern and process, theory, and practice is important. The IPT workshop protocol provides one way of greatly attenuating the learning curve. Non-professionals can quickly acquire a useful level of understanding. For example, Chapters 3 and 4 discuss the functioning of rangeland ecosystems, while the explanation of the Range, Livestock, and Wildlife model which accompanies the flow diagrams in Chapter 5 are a primer on the topic. Participants will understand the contributions which are necessary from disciplines linked to the range sector, and the necessity of studying and managing resource

systems. The workshops and participants' evaluations have repeatedly demonstrated the educational potential of IPT.

Education of both the participants and facilitators is a predictable product of a well-run IPT workshop. Of particular use is the identification of specific links between disciplines and sectors which had not yet been clearly identified. These are specific portions of the system which require cross-disciplinary information exchanges for good planning. This exchange is not only a general, long-term educational benefit of viewing whole systems and enfranchising under-represented essential disciplines, but the true interdisciplinary nature of the workshop produces a better product.

However, the significance of enhanced understanding and judgment about systems processes transcends any particular project. The most effective use of IPT workshops may be as an education medium for development professionals in donor agencies. These people are often highly trained in one science or skill, such as economics or management, but may lack a background in ecology or applied sciences.

1.6.8 Environmental Data and Resource Assessments

Attempts to inventory data and record historic trends for natural resources and environmental issues can be expensive and time consuming. A variety of environmental profiles, conservation strategies, environmental assessments, and environmental sector reviews (among other labels) have been

produced. These efforts attempt to document the environmental statistics, analyses, and recommendations which should be available for use by resource policy makers, planners, and to a degree, scientists. These documents are useful because the facts required for informed decisions and planning are rarely available in such an accessible form.

However, after a recent surge in production, these documents are candidates for improvements. Some contain old data or data in a variety of units and scales. Most data are aggregated and of limited use to a project planner concerned with pattern and process at specific sites. Data in some do not appear in others, making regional analysis difficult, and most data are of suspect quality. Furthermore, the reports and the information they contain are generally frozen at the time of production and are not easy to update. The data in the reports are not interactive with the user, nor can their supporting data bases be queried for original data which is useful at some levels of development planning.

Perhaps the most difficult task in producing such inventories and analyses is deciding what data are important to include. This can be an eccentric process reflecting the knowledge or interests of the parties planning the document. Important data may be omitted and superfluous data included.

To enhance the utility of such profiles and assessments, they should include contributions from diverse experts, but in a way which:

- removes personal bias or personal research interests,
- is inclusive beyond the sum of individual knowledge (this is the only way many links in a system can be identified), and
- selects the most important items from a large constellation of information.

A model should embody the minimum subset of elements required to achieve a desired level of understanding or analysis. The IPT workshop will achieve this distillation, yet be inclusive because of the protocol which structures the identification of all significant elements. One of the products of the conceptual model developed at an IPT workshop is a list of model elements (variables and parameters), and the units used to measure these elements. Eventually, sensitivity analyses of the simulation model will prioritize these model elements by how important they are to the realization of system goals. The data search will reveal the data which are missing and of questionable quality. In this way, IPT can generate an unbiased, objective list of data requirements for planning, as well as prioritize these requirements. The data search and sensitivity analyses will produce an objective estimate of the importance of data and processes as well as a subjective assessment of information quality. The data base which contains the information can be accessed interactively (e.g., by modem) for the most current data sets.

Another obvious IPT use is to identify specific links and points of cooperation among the authors of a profile or strategy. This is an effective use only if it occurs at the earliest stage of research and production of the document. An IPT workshop is needed to identify the system structure, elements, and interactions. We once attempted to use IPT to point authors toward each other after they had completed their discipline-specific contributions. Predictably, nothing changed.

1.7 Who Might Find IPT Useful?

1.7.1 Donor Agencies and Development Institutions

Development goals change over time, even over the life of a project. Since the 1950's, USAID has changed its emphasis from extension and training, to capital-intensive infrastructure development, to rural development, alleviation of poverty, and sustainable resource use. Gradually, capital transfer and the management of this process became a very important concern at the Agency. Such concerns are reflected in a reduction of technical staff and an emphasis on managers, accountants, and economists (Freeman, 1988). Environmental concerns are a new factor. These changes will not deflect the need for systems planning tools, whatever the system is. In fact, the need for a very efficient use of technical insights may have been enhanced by relative reductions in technical staff. Although goals may evolve, the requirement to plan for achieving these goals does not. Given the diverse nature of Agency staff, a planning process which offers a common language and a clear history for different future users is a tool to enhance communication.

IPT is also designed to integrate the varied styles and knowledge of the different guilds within the Agency which must cooperate to plan a project. As described in Chapter 3, the use of IPT helps to organize planning in a logical fashion by using a workshop, a precisely defined protocol in the workshop, and a common language.

1.7.2 Research and Training Institutions

An obvious role of the IPT workshop is to identify the most critical elements of a system and then prioritize them by the contribution they make to the functioning of that system. The workshop protocol ensures the a logical and economical approach, and is essentially a research identification exercise. In addition to the utility of the systems approach, the public modeling is an economical method of acquiring knowledge about the system and learning to be productive in an interdisciplinary and often intercultural setting.

An example of the benefits the IPT process can bring to a research organization was demonstrated at a 1986 workshop for research officers of the Namibian Nature Conservation Department. Twenty biologists and veterinarians examined the problem of rabies in kudu, a commercially important game animal. One officer had been investigating this issue for nearly two years. Workshop participants proceeded through the protocol and defined their goals, issues, system structure, and variables. After attaching units of measurement for the critical variables and parameters which the research group had identified, they discovered that less than half of the data points required were being investigated. The model had not been logically developed before the data were collected. Data were lacking for many of the important variables and parameters they had just identified

as the critical information set necessary to understand and manage the problem.

The IPT workshop in Namibia exposed an instance of such inefficiency. Time and resources had been unnecessarily squandered. The workshop should have preceded the work and helped focus it. Other data collection and collation efforts suffer from such a shotgun approach, and the resultant lack of focus and decay of analytic capabilities.

1.7.3 Resource Managers

Often those who are charged with managing resources are also involved in the management planning. They need the best planning and management tools. The use of IPT, particularly participation in the planning workshop, will enhance the managers' understanding of the system being managed. Ultimately, any process which clarifies the consequences (system behavior) of management actions and helps to explore management alternatives is of value to a manager.

In addition to the simulation model, characterizing the system facilitates the production of other managerial tools such as critical path management products (work calendars, budgets, milestones), and better identification of staffing requirements.

The utility of IPT to managers was also demonstrated at a 1985 short course for mid- to upper-level forest management officers from 24 countries. They examined the forestry model

structure which had been created by the USAID foresters. Two small but possibly significant amendments were suggested:

- examining the contribution of political support for a forester to general forestry goals (such as increased timber sales), as reflected in increased tenure at a posting, effectiveness, and other capabilities; and
- testing the effect on forestry goals of continuing education opportunities such as the one in which they were participating.

We compared the effects of these two policies on forest management and found them to be significant. The relative benefits of each policy were then compared. Such evaluations were of obvious utility to those managers who seized upon the approach as of great potential in their work.

1.7.4 Policymakers and Planners

Many of the comments describing the uses of IPT to donors apply to policymakers as well. An example is the efficacy of different, alternative approaches to game ranching, product diversity, land management, and research generated by our application of IPT to the Buffalo Range Ranch in Zimbabwe, described in Chapters 5 and 6. This would be of particular value to policy formulation by the ranchers. However, macro-policy models treating national and regional issues would aggregate such specific evaluations for policymakers at national or regional levels. The workshops and their products would also focus on sub-sectors not incorporated in site-specific examinations (such as macroeconomic links).

In the application of IPT to larger policy issues, the effects of political motivation, exogenous inputs (e.g. international economic policies), random events, and other variables and parameters difficult to control or objectively assess, bring IPT analyses closer to such early applications of system dynamics as industrial and urban management, and global limits to growth. IPT is also useful in these larger policy areas because it captures less predictable and more subjective parameters and insights during the workshop.

1.7.5 Resource Users

User construction renders IPT unusually useful for the stratum most often ignored in planning -- farmers, fishermen, and ranchers. The consultation necessary with IPT represents an attempt to accommodate the visions of a system which may be unique to a place and the people in it. This involves perhaps the most important parties in the planning process, who are often not consulted. A method for soliciting informal but important knowledge from local users has always been elusive and is often ignored at the risk of informed planning. Highly trained western scientists have particular difficulty in accessing useful local knowledge. The value of such information has been repeatedly confirmed. An example is the utility of customary law (adat) in Indonesia for informed planning. By involving local resource users in the workshops, the process can take advantage of their perspectives and knowledge.

Chapter 2

THE BASIS FOR DEVELOPING IPT

		Page
2.1	Immature Uses -- Causes and Consequences	52
2.2	Use of IPT in New Problem Areas	53
2.3	Uses of Structure	55
2.4	Time -- Using Systems to Analyze Dynamic Problems	58
2.5	Feedback and Control in Ecological Systems	61
2.6	Style: Differences in Planning as a Paradigm	66
2.7	Three Generations of Planning	72
	2.7.1 First Generation - the Dominant Expert Monoculture	72
	2.7.2 Second Generation - the Modular Multidisciplinary Team	72
	2.7.3 The Next Generation: Interdisciplinary Planning for Integrated Systems	76
2.8	Models Featuring Structure, Time, and Feedback	78
	2.8.1 Definitions and Uses	78
	2.8.2 Different Uses of Different Models	82
	2.8.3 Can We Trust Models? If Not, Can We Use Them?	86

2.1 Immature Uses -- Causes and Consequences

Integrated Planning Technology (IPT) is a means to improve planning for natural resource conservation. As such, it is only a tool -- one which can be misleading if misused without a real understanding of why it was selected. Likewise, impatience to generate results may lead a user to skip necessary steps, which would be analogous to not reading the instructions on the box. Either omission can lead to what we describe as immature uses.

Therefore, before describing the mechanics of how IPT works, an examination of its foundations is important for full understanding and proper application. Because of IPT's power (through its logic, sophisticated software, predictive capacity, and quantitative expression), misuse could be just another form of bad planning. IPT is based upon the ability of the resource planner and scientist to make best use of the tool. Their training and experience should help ensure they will not become prisoners of the technique, or merely fancy tool-using mechanics. In this chapter, we attempt to reinforce existing technical capabilities with the basis for the systems approach we are suggesting. A desire to immediately use the model should not short-circuit an appreciation of its foundation.

2.2 Use of IPT in New Problem Areas

The application of general principles is of greatest benefit when solving new problems and working in unfamiliar areas. Presumably, general theory is portable while specific observations might not be. Systems theory is an excellent example of an adaptable and broadly useful body of knowledge for the natural sciences and for natural resources management. For example, the concepts of structure, feedback, stability, and other features of systems mentioned in this book (particularly Chapter 3), are useful for understanding any natural system. The IPT process is designed to exploit common attributes of systems to produce analyses for renewable resource managers. Furthermore, the process incorporates a protocol which efficiently extracts relevant information about the system under examination from the wide variety of participants which the process requires. It does so by using systems theory at precise stages in the IPT process through the protocol. This process identifies the smallest useful set of key questions and the information required to answer them, and filters out extraneous knowledge. In other words, the IPT process can help identify and use old knowledge for new discoveries or novel applications. We call this attribute "bootstrapping" your knowledge.

Early, less managerial societies simply adapted in response to what were believed to be divinely managed systems beyond mortal control. As agricultural and industrial societies emerged

and natural systems required manipulation, management responsibilities dictated an understanding of how productive systems worked. Understanding and managing productive systems have always been closely related in the applied sciences. Unfortunately, management can occur with little or no understanding. The divergence of management and understanding varies over time and within different organizations. A link between experience, accumulated knowledge, and good management is posited. Furthermore, as the cost of failure increases and is more directly borne by the planner and manager, inadequate understanding and poor management are more vigorously addressed.

The need for understanding has generated both a search for better ways to describe systems (their structure), and a search for general principles to clarify how they function. The effort to understand systems has led to discoveries of unimagined and subtle complexities and vast accumulations of descriptive data. The search for systems understanding has tended to overwhelm the discoveries, paradoxically frustrating the investigator whose files overflow with the accumulated products of the search.

2.3 Uses of Structure

Without organizing the component parts of a system, structure does not exist, and goal-directed functioning of the system is not possible. Without organization, knowledge is for collectors, not managers or scientists. Forrester (1969) describes the observations of Brumer (1960) on the educational value of structuring information. Brumer believes that grasping the way a structure is organized confers understanding of how other things are related to it. Furthermore, understanding the components of structure and how things are related insulates the observer from being intimidated by complexity. By structuring a system, less important elements can be dropped and the structure can be simplified for better understanding. Therefore, teaching structure and relationships is important for less (or normally) gifted observers -- which describes most of us. Since systems have goals toward which their many elements function, organization of their structure is critical to first simplifying the system (a model) and then understanding it. Dealing with systems is important because most of us need to understand enough about the systems we must manage every day to achieve goals for our family, investments, business, woodlot, or lawn.

Simple observations of the environment, and the ensuing appropriate reactions, involve in the most primitive case repeated, often sequenced, familiar tasks. In many animals, such as birds, the behaviors are ritualized. Learning by rote, imprinting, and stereotypy are examples of this simple form of

observing, classifying, and reacting to observations. A second way of learning, according to Brumer, is through the transfer of principles, which is predicated upon first mastering the subject's structure by observing not just environmental pattern, but understanding process as well. Teaching for understanding involves analyzing the structure -- the elements, cause, effect, relatedness, and feedback -- which can uncover the process. Understanding is the prerequisite for managing the structure. Brumer also notes that understanding structure can place details into patterns which facilitate memory or recall of the facts. Research has demonstrated that classification helps memory, and without such a structural pattern, detail is quickly forgotten. The method which has evolved for observing systems and discovering structure and function has been formalized in the scientific method, of which IPT is an emulation (See Figure 2-1).

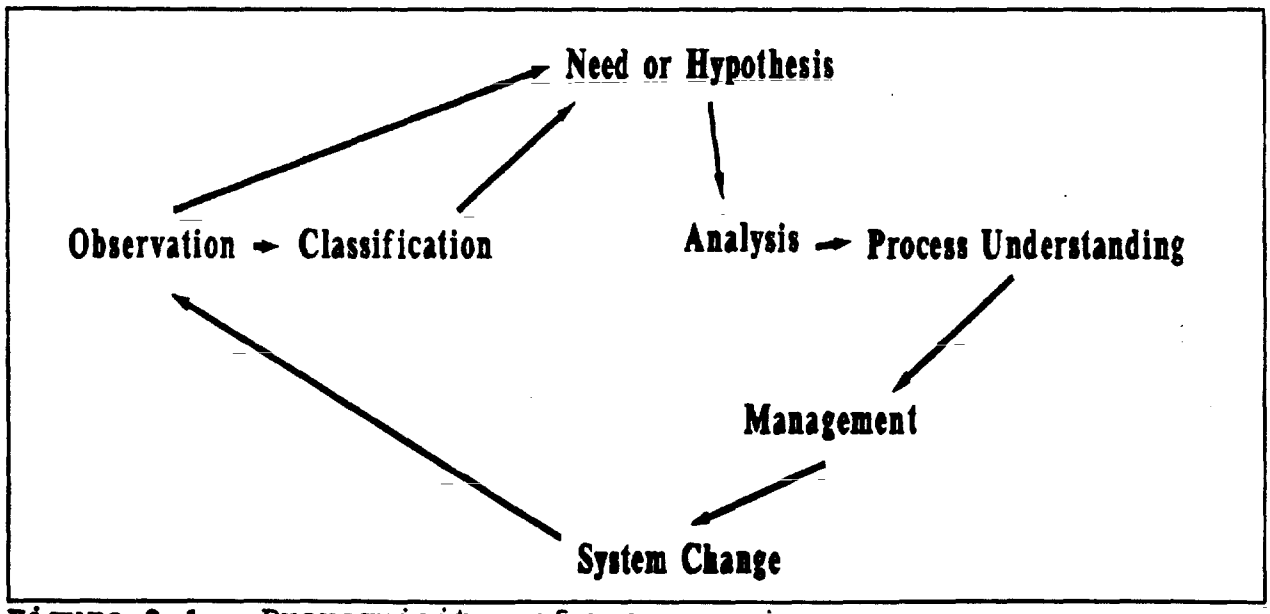


Figure 2-1. Prerequisites of management.

Examples of structure and the necessity for structuring systems are common. The Linnean binomial system of classifying plants and animals hierarchically to reflect genetic and evolutionary relationships is an example of organizing a potentially overwhelming structure (there may be over 30 million higher plants and animals to be classified). We can then begin to investigate functions or processes which control the systems comprised of some of these plants and animals.

2.4 Time -- Using Systems to Analyze Dynamic Problems

Efforts to understand systems are not only complicated by structural complexity. The passage of time brings change, and it is important to observe how the system changes in order to understand its structure, relationships, and processes, particularly if we wish to manage the system. Dynamic behavior simply means change over time, and the analysis of changes in natural systems is clearly important. Development projects span a time period, yet many important management decisions and project designs are based upon baseline snapshots -- a fatal flaw of many feasibility studies which describe the natural resource base. In fact, the terms planning, stability, and prognostication imply a temporal element. An example of the complexity introduced when system dynamics are used in planning includes time lags in cause and effect. A predator and its prey, or pollution and dilution, do not generally change simultaneously in the same direction. Over-exploited prey become extinct before their obligate predators. We worry now about the eventual consequences of such time lags with the greenhouse effect.

The analysis of change is further confounded as different elements in a system change at different rates. Differences of scale which are critical to understanding a system are often overlooked. Soils, plants, and animals are elements of some natural system structures. However, soils may take one thousand years to return to an initial state, plants may require ten

years, and animal populations, two or three years. It is difficult to find many studies which have objectively monitored change over time. The model validation of a range system reported here used data recorded over twenty-six years at the Buffalo Range Ranch in southern Zimbabwe to capture the dynamics of the structure. These data, however, are a rare example of record keeping fidelity.

A fascinating example of the effect which the choice of temporal boundaries and scale have on natural resource development is described by Ellis and Swift (1988). The dominant paradigm for African pastoral systems is an inherently stable rangeland system controlled by density-dependent feedback controls, stability through diversity, adaptive fine-tuning through evolution, and other familiar ploys of Mother Nature. In this generally accepted view, the equilibrium is upset by the scramble for scarce common resources (such as forage) by increasing numbers of pastoralists and their livestock, which lead to overgrazing, desertification, ecological refugees, etc. Ellis and Swift challenge the assumption of a dominant equilibrium, and contend that pastoral systems are upset by large-scale, longer-term destabilizing forces of climate, or reinforcing and therefore destabilizing strong feedbacks. Acceptance of the stable system paradigm by development assistance agencies (for example, a three-year project) can explain their consistent failures in the range sector. Ellis and Swift contend that pastoral systems management efforts employ the

wrong paradigm, a poor model, the wrong boundaries -- an example of the importance of understanding process and dynamics, as well as pattern and structure.

Field work in natural resources, whether in support of research, project implementation, or commercial property management, is not a tidy activity. Natural systems such as rangelands invariably surprise even the well-prepared planner. Only with transformation to tame cultures such as a hay or bean field can a degree of mastery be forced. The systems approach described here is another way the student can whittle away at the unpredictability of natural systems whose structures have not been observed over a time period sufficient for good management.

The IPT workshops, which are described in detail in Chapter 3, and in fact the entire IPT process, were developed to accommodate and reflect the peculiar requirements of the applied natural sciences (such as forestry, fisheries, agriculture, range, and wildlife) which deal with the greater complexity, dynamism, and unpredictability of natural systems. They contrast with physical systems which have been transparent to the mathematical models and predictions of a Heisenberg or Einstein. IPT elicits communal insights which depend upon the participants, rather than individual brilliance.

2.5 Feedback and Control in Ecological Systems

Many efforts to solve a problem respond to a mental model of an open system. Typically, in open-system planning a problem is perceived, a remedial action occurs, and a solution ensues. Generally, the effect from the outputs of the action (the solution) is not assessed for its influence on the original state of the system and its problems. In other words, the problem solver assumes that the system has no memory. The outputs have been isolated from the original system and its problem and the problem solver moves to other issues (See Figure 2-2).

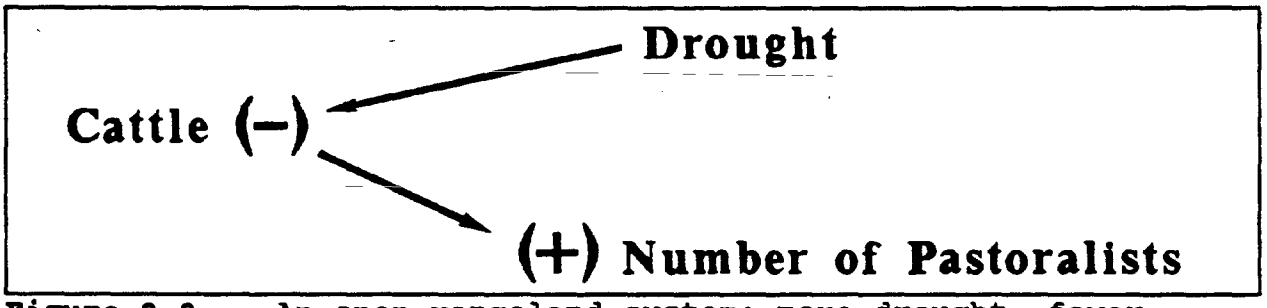


Figure 2-2. An open rangeland system: more drought, fewer cattle (they change in opposite directions, hence the minus sign), fewer pastoralists (they change in the same direction, hence the plus signs).

An open system does not react to a changed state, and is unaware of its performance. There is no feedback. An open-system solution to the situation represented in Figure 2-2 might be the provision of food since it assumes that drought cannot be managed, or that changes in pastoralists do not cause changes in cattle or drought. As an example of an open system, Forrester

(1969) notes that a watch does not observe its inaccuracy and adjust itself. It is an open system, and exhibits no feedback.

However, many management efforts to control system outputs involve the general occurrence of feedback loops whether they are considered or not. Not enough is known about the system in Figure 2-2 to properly manage it. Figure 2-3 shows that the population of pastoralists responds to the availability of food, which responds to drought. However. the management strategy must consider a more comprehensive picture which may not react as open-system planners tend to believe.

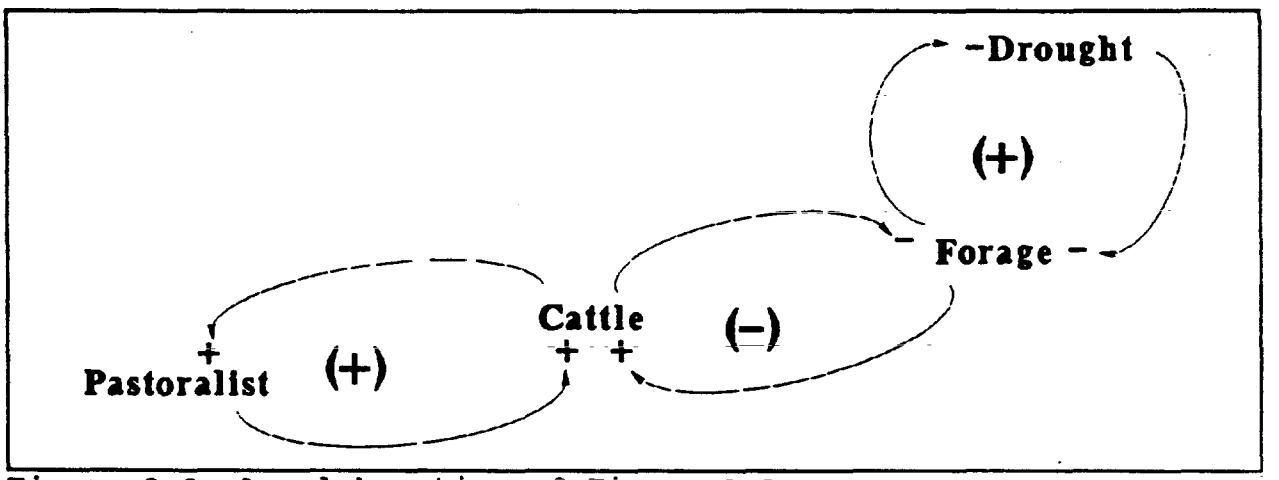


Figure 2-3. An elaboration of Figure 2-2.

As cattle increase, so do pastoralists, and the pastoralists keep buying cattle. Cattle and pastoralists increase or decrease together (hence the "+" sign), which means both can increase explosively or decline to extinction. Similarly, as drought increases, forage decreases, and as forage increases, drought decreases due to reduced reflection from the bare ground and more

rainfall, as well as the ability of perennial plants to capture more precipitation than the annuals which result from overgrazing. The sum of both negatives is a positive. Once this subsystem is actuated, endless forage enhancement and drought elimination, or an increasingly dry environment and forage elimination are the only possible outcomes. The system is given stability by the negative feedback of the cattle-forage system, which can control the whole oversimplified pastoral system in Figure 2-3. As depicted, drought-related decrease in forage will reduce cattle, but fewer cattle will permit forage to recover (they are inversely related, hence the "-" sign). If assistance maintains cattle during drought (or raises the number of cattle above carrying capacity in wetter years), this forage-cattle feedback control is eliminated at the risk of fostering endless droughts. It becomes an open-system solution based on Figure 2-2 which emphasizes cause and effect but omits feedback.

The policy and management approaches available to each of the different managers (open or closed systems) are also different. An open-system manager might import or supplement forage during a drought to sustain the cattle population. A closed-system manager would attempt to provide long-term alternatives or amendments to cattle keeping, perhaps commercial game harvest. IPT would be most useful for closed-system management environments, but most resource issues are approached as an open system in a direct, sequential, and linear way. Changes over time are not incorporated to reflect the dynamism

and time lags anticipated in the system. The common approach is to fix the problem and move on.

The African ranchers we visited do not measure the subtle responses of the range to a dry year. The accumulated effects on range condition and income over the years are not reflected in the current one-year-at-a-time planning and management by the operators. They have not closed the loop. The deleterious open-system feedback effects described in Chapter 6, Section 6.3 sneak up, and in effect, constitute a time bomb.

Many projects have suffered this approach. The Mahaweli planners (see Forward) did not anticipate feedback. The consequences of fuel requirements, the resulting uncontrolled fuelwood harvest, forest depletion, and ultimately the effects of exhausting fuelwood supplies and burning crop residue and manure for fuel were not anticipated. As a result, soil tilth and food production were reduced. Migration from the farm to new towns in the project command area was another unforeseen result and, therefore, not planned for, with resulting shorfalls in schools, clinics, public finance, and infrasctructure.

Development assistance projects do not typically plan for systems, much less closed systems. Planning does not feature project or program responses to the altered states generated by the project itself. The logical framework ("Log frame") often used for mapping the assumptions, conduct, products, and assessment of a project does not emphasize or incorporate closed-

loop planning as described here. Current practices foster a linear, open-systems problem-solving approach -- e.g. spreadsheet projections. As individuals we remember, evaluate, and are influenced by our own performance, but curiously we do not always behave in as careful or reasonable a way when we plan or evaluate our projects.

2.6 Style: Differences in Planning as Paradigm

Professional specialties may employ identifiably consistent planning approaches (See Chapter 3, Section 1). Do engineers, or lawyers, or ecologists each have their own approach to conceptualizing and solving a problem? Do preconceptions flavor and bias the observations and interpretations which are applied to a problem? Even statistical procedures do not cleanse a study of the bias which each school or guild brings. Different schools of modelers also bring their world view, approach, or paradigm. Meadows (1980) pointed to the pitfalls of selective blindness, competitive approaches, and mutual disdain of different schools of thought.

Ecology also has a point of view. Ecology is a science which reflects the power of synthesis and interactions in an ecosystem, and systems analysis was a natural path in the evolution of ecological science. IPT must be influenced by our own underlying assumptions and backgrounds in applied ecology. However, one function of the IPT workshop is to elicit and use the perspectives of all workshop participants. Participants can be quite explicit, for example, in describing their best *a priori* guesses of system behavior. The participation of every guild or point of view germane to the issues and system is designed to greatly reduce bias, which compromises many centrally planned efforts.

There may be several explanations for bias. First, it could be hubris -- such a firm belief in one's own knowledge and capacities that contributions from others seem presumptive, inconvenient, and redundant.

Second, the daily pace and pressure of business on a development planner can be so great that inventorying and securing technical consultants is a hassle, and can appear to impede rather than facilitate progress. This leads to the cozy short list, which implies that several wise consultants known to the planner can provide all necessary insights and services. In fact, it may be very difficult to find consultants with certain technical skills and the corresponding foreign language capability or experience. There tend to be many Spanish-speaking wildlife biologists, but not many environmental engineers who speak Indonesian.

Third, the operating paradigm influences the targeted needs. A planner without experience appropriate to a specific project may make management errors, as described in the discussion of system understanding above (2.2). Often, the help necessary to plan a development project is not sought, which abridges or diminishes the technical consultation process.

Finally, the policymaker/planner and the technical expert often have problems communicating. The knowledge of a scientist can be an important contribution, but a good researcher may not have the ability to communicate the research. Communication

problems may be compounded by divergent agendas. A research biologist may be interested in the natural, unmodified system and in supporting graduate students to study it. The developer is interested in altering the system for some greater economic good. The world of international development assistance is opaque to many research scientists, which can make mutually useful interaction and communication difficult. Likewise, the developer can be immune to the insights and desires of the end-user or presumed beneficiaries of projects. There are several different world views to be identified, if not reconciled, for effective support and communication to occur during development planning.

Management responsibilities, environments, and styles are different in organizations as diverse as various international agencies, private sector groups, and families. The focus is different, and the project control for each group is very much a reflection of both focus and culture. The manager of an international organization must deal with many people of various backgrounds. The head of a family deals with a few people who are more homogeneous. Planning, coercion, review, accounting, and other management-related tasks are often much different. Vertical planning involves people at various levels who are all important to a project's success. Ministers must understand an activity which competes with others for attention and support nationally. Any development activity will generally be important to a larger strategy not always evident to those at the point of application. However, those on the ground have knowledge which

is important to the goals, and therefore focus, of an intervention. They may well be the essential source for defining the structure of the system.

The failure to solicit and use indigenous knowledge is common. The planner often assumes adequate knowledge of goals, attitudes, and decision-making processes and decides what is best for the people being targeted as beneficiaries. For example, "adat," (customary law) in various areas of Indonesia determines what is possible (Zerner, 1987). In such cases, project acceptability suffers because local "ownership" was not generated by participation in planning the project. The Chiredzi, Zimbabwe ranchers with whom we had an IPT workshop (See Chapter 5) reinforced this impression of a current emphasis on top-down planning. We were told that participation in our workshop, although inconvenient (some had to travel 150 kilometers a day on dirt roads to attend), was partly in response to the highly unusual fact of our mere presence. The planner and technocrat have much to gain from such local consultation. Numerous IPT workshops have demonstrated to us that any single workshop will omit something important. Although omissions are often obvious, important endemic contributions are not often anticipated. An example is the importance of game purchases to the wildlife stock on game ranches in southern Africa. Birth (but not purchases) had been assumed to be the only source of increases in wildlife numbers. A workshop in Botswana proved this assumption erroneous.

As described earlier, system dynamics was used to improve the planning and management capabilities of industrial organizations. IPT is being developed to do the same for international development assistance agencies. Incidental to this original goal for IPT, the necessity of dealing with real cases, such as the management of a ranch, demonstrated how the focus could change. We saw how micro uses could be extremely important to developing IPT's application to more extensive uses (for example, regional) -- an information flow generated from the bottom-up with the IPT process.

In this sense, IPT is a vehicle to vertically integrate planning and to use the diverse styles and knowledge of the various parties to planning. AID needs to be very well informed about the goals, problems, and systems of target groups to plan its own interventions. At the management level, knowledge of other strata becomes essential for communication. People will need to deal with each other -- from the developer to potential beneficiary. Does the developer (e.g., project manager) have an open-system paradigm while the farmer perceives closed systems? Can they communicate? Each would likely define the same problem and potential solutions quite differently.

This brief discourse on the unfortunate, often costly, communications gap between planner, user, and technical staff is offered to clarify some of the motives behind the design of IPT.

To be useful, IPT should not only consider systems, but must also bridge disciplines and cultures by:

- providing a common comprehensible language, and
- providing a process which can identify important but often overlooked planning milestones necessary for technical research and analysis. For example, the IPT process, if logically and sequentially undertaken, will help tell the scientist the variables to investigate and the boundaries of the investigation.

There are other means to bridge the policy/technology/user gap. However, some of these approaches, such as technology short courses or scientist/planner site visits, are too often deferred because of the daily press of business, or the lack of immediate application to a real problem of the participant. Required in-service training currently tends to emphasize project management and evaluation, high-profile conservation issues, the office environment, or the politics and protocol of international development (Freeman, 1988). A systems overview which selects and develops certain specific details of different fields can provide a common language and educate the policy and planning experts, the resource scientists, and the on-site users so they can communicate effectively.

2.7 Three Generations of Planning

2.7.1 First Generation -- the Dominant Expert

In the first generation of development planning, projects were designed and implemented by experts from a single discipline who ignored most factors outside their discipline. The Mahaweli River Basin Development Program was designed to store and distribute water in generally undeveloped dry areas of Sri Lanka for hydroelectric power and rice irrigation. The project was planned by engineers who built impressive structures designed to do what they are supposed to do with the water. But there was a downside to this development -- unforeseen effects and consequent costs to humans, and the economy and ecology of the area. The gradual perception of these unforeseen ripple effects changed the approach which was used during this first generation: planning dominated by a single discipline such as civil engineering or wildlife preservation (more often the former).

2.7.2 Second Generation -- the Modular Multidisciplinary Team

Single-discipline planning produced a painful mix of anticipated success and unanticipated problems. The concrete in a dam would harden and the waters would rise, but the dislocation, river blindness, reduced flood plain productivity, estuarine erosion, loss of biological diversity, boom-bust construction economy, blocked wildlife migrations, required enforcement, and a host of other consequences, soured development and gave the single-discipline planner a bad name. To take one

type of enterprise, the litany of failed game ranching enterprises in East Africa (See Chapter 4, Sections 4 & 7) is a good example of poor, or more precisely, incomplete planning. Almost every one of these failures was avoidable. Potential problems were entirely predictable if the right people had been part of the planning. They would have known that shooting all the elephants around a fixed-base abattoir would increase transport costs, or that animals would seasonally migrate out of a harvest command area, reducing the off-take.

The most obvious reaction to such focused development was recognition of the broader planning requirements of whole systems. Experts representing disciplines that reflect the major resources of a system to be developed assemble in a team. The multidisciplinary team approach is an effort to minimize the unexpected impacts of development by attempting to account for nearly everything of potential significance which a system might incorporate. This approach became increasingly popular over the last thirty years and is the current typical planning strategy. Planning of the Mahaweli actually transects the transition in planning approaches from the dominant single discipline to multidisciplinary. The Mahaweli did not enjoy the perspective afforded by a multidisciplinary approach when planning began about thirty years ago, but recent amendments to plans have attempted to rectify potential problems related to single-discipline thinking. For example, USAID supported the first environmental assessment of the Mahaweli project in 1980 -- after

twenty years of planning. Of course, the assessment could have no fundamental contribution to make in project siting, construction technologies, or other project features and activities planned twenty years earlier. Instead, it had to explore the environmental mitigations still possible. It became clear that the endangered Asian elephants would soon find the food provided by new farming in their home ranges, and a confrontation of elephant and farmer was virtually set up by the project. A massive and costly animal damage control problem is quite likely, similar to the problems encountered by migrants to Sumatra, Indonesia, who were located in elephant range (Seidensticker, 1983). The Mahaweli environmental assessment resulted in protected areas to harbor many of the elephants, thereby mitigating some effects of the project (TAMS, 1980).

Concern over the single-discipline approach led, in part, to the regulatory requirements for a "systematic, interdisciplinary" environmental impact assessment process in the United States. The National Environmental Protection Act of 1970 initiated the environmental assessment of projects, focused on multidisciplinary planning, and with modifications, soon spread to other parts of the world (Berwick and Soewardi, 1991). One large environmental assessment project on which the first co-author worked employed over four hundred scientists and engineers from numerous disciplines working on thirty-four different areas from quality of life to range management. Unfortunately, the multidisciplinary approach and the press of deadlines does not

ensure that these resource-specific analysts speak to each other to identify key links. The wildlife biologist must find out from the demographer how many in-migrants will use wildlife resources. The biologist will then ask the sociologist if in-migrants will hunt for meat or trophies, which are often different animals. Only with extensive consultation and data exchange at the right time can an impact assessment of the wildlife resource be developed.

However, what happens is generally much different. Consultations are informal, the specific links are not identified by any objective process and are likely to be overlooked. Under the production deadline pressure, the scientist works on the topic until just before due date, and that one part is bound as a module with the rest of the resource assessments. Although the process was multidisciplinary, it was not really interdisciplinary. An organized, timely, iterative, interactive information exchange is rarely accomplished. The impact assessments produced in this way give an eccentric and modularized view which can not reflect a world in which the bits and pieces somehow work together. The result is a strange view of the current state of the resource. The predictive power of the analysis of the projected impacts is very much reduced and suspect. The lack of integration precludes identification of feedback and ensures an open-system approach to complex closed systems. However, at least the various elements did receive consideration, which is a step forward from the single-discipline

emphasis of the first generation. Problems with multidisciplinary planning are evident in the large river basin development plans which rarely work as planned. These include the Gambia and the Senegal of West Africa, the Mekong of Southeast Asia, and currently, the Narmada of India (See, for example, Freeman, 1974).

2.7.3 The Next Generation -- Interdisciplinary Planning for Integrated Systems

In spite of general agreement on the need for true interdisciplinary ("holistic") approaches to planning, examples are rare, while there is abundant evidence of the costs of not doing so. Multidisciplinary planning is straightforward. It requires a team and reports at the end of the planning process. Interdisciplinary planning requires new, more sophisticated tools. The gap between the desire for interdisciplinary planning and actually using interdisciplinary methods persists at AID and other institutions for many reasons: lack of the necessary technology, fear of the technology by some users, lack of a mature and tested approach, and other reasons discussed in greater detail in the first chapter. Very few concentrated efforts have addressed the specific multisectoral and interdisciplinary requirements of international development. Very few efforts have been able to shift the creative aspects of modeling from the trained systems analyst to the end user. Likewise, a minority of planning or modeling approaches employ feedback to close the system, thus enabling the system to be

aware of its own state and trends. This time-dependent feedback is necessary to achieve system stability.

2.8 Models Featuring Structure, Time, and Feedback

Models are simplifying representations of real-world systems. For natural resources, a real system is described by elements and processes which are infinitely complex. Systems are often simplified most efficiently when models are designed to address specific problems of the system.

Models can be used by scientists much like spectrophotometers, binoculars, or other tools. However, unlike other tools, their creation depends upon observing the protocol of the scientific method described at the beginning of the next chapter. We use these models, or distillations of complex reality, not only to help us better predict system responses to interventions, but also because the process helps us organize our thoughts around the system's structure and problems with it. The process also generates new understanding and can provide a tool to test that understanding. Structuring knowledge and information in a patterned way organizes confusing detail, which fosters understanding principles, rather than memorizing details -- the prerequisite for problem analysis (Brumer, 1960).

2.8.1 Definitions and Uses

The vast majority of models in use today are mental models of the environment of individuals for people confronted with the need to understand or make a management decision about that particular environment. Daily decisions addressing such near-term requirements as reproduction, feeding, and survival, as well

as longer-term requirements such as investments, culture, and management, are based primarily upon the mental models formed through experience and education.

Complex problems and environments may require more complex and formal models, which have some advantages over mental models. They are more explicit and are documented on paper (or should be), exposing the construction process, encoding algorithm, data used, and assumptions. Hence, they are easier to communicate, reformulate, and improve. Formal models can also be translated into code for use by computers, further enhancing their utility because of the rapid treatment of computational complexity made possible by the computer.

Holling (1978) diagramed the interplay of data, understanding, and complexity (See Figure 2-4). Adopting Holling's classification, the region of good understanding but poor data (region 2) is encountered in numerous sites and projects. Examples include many developing country sectors where inventories are lacking and very little information specifically applicable to a site is known, but much work has been done on analogous systems elsewhere. For example, comprehensive research has been conducted on rangeland systems at several East African sites, or on coral systems on the Great Barrier Reef of Australia. These two systems are representative of similar systems elsewhere in the world which face development challenges, however. In some of the very complex natural systems which have

been investigated, understanding remains low, and more (or better) work must be done (region 5).

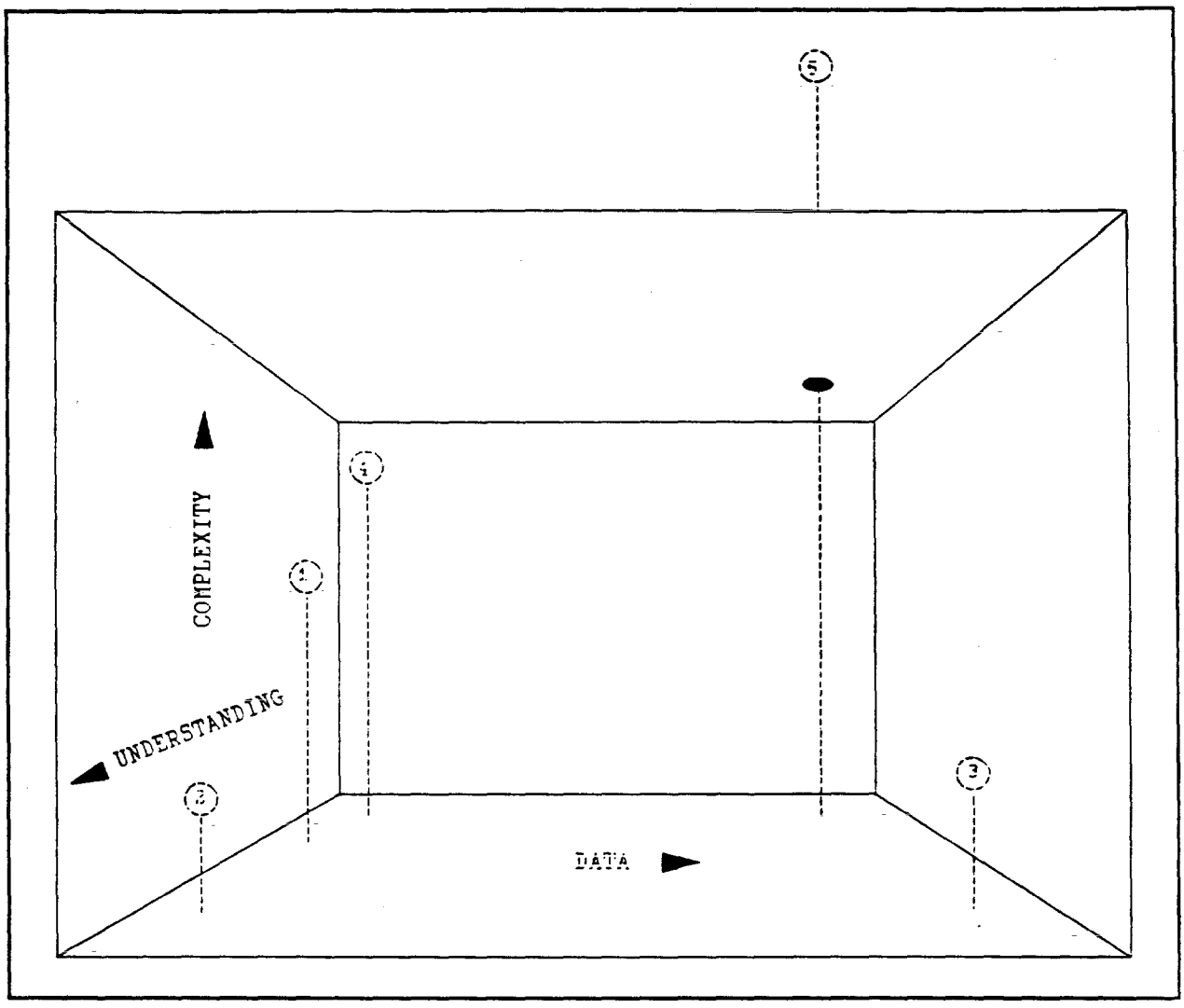


Figure 2-4. The relationship between increasing understanding, complexity, and data characteristics of certain areas. These domains are particularly suitable to a specific mix of analytic and management approaches (after Holling et al., 1978).

In the domain of good data, good understanding, and low to moderate complexity (region 3), we find many of the engineering problems so successfully resolved using physical and mathematical

models. Examples are applications for military weapons and construction, space exploration, nonrenewable energy development, and process management.

Areas of poor understanding and/or poor data (regions 1 and 4) tend to describe the condition of the renewable resource sciences, particularly systems dominated by biological and cultural elements. These are the most commonly encountered important systems in development assistance, and are the least tractable using traditional approaches. Policy, planning, and management decisions are often made under the stresses and urgency of immediate needs. How are sound, objective decisions to be made with poor data and little understanding, particularly in the extraordinarily complex developing tropics? The luxury of postponing development decisions until the data are assembled is not often an option. The models and methods described are efforts to improve understanding and focus data collection. One curious but consistent response to the lack of understanding described by regions 1 and 4 is to collect and accumulate all data on a topic without much analytical focus for specific problems. This leads to a region 5 situation.

The IPT workshop in Namibia described earlier (Chapter 1, Section 1.7.2) exposed an example of such inefficiency.

Another example of an undirected response to predictions of poorly known environments and processes are the pre-1977 environmental impact assessments conducted in the United States.

Before the 1977 regulations, a paper blizzard produced overwhelming (and often useless) amounts of raw data used as filler in the assessments. We suggest that an Integrated Planning Technology be used to focus on the data collection so that the key questions can be objectively and credibly pursued (Berwick and Soewardi, 1991).

2.8.2 Uses of Different Models

There are a variety of modelling approaches which respond in different ways to different uses and requirements. As context for IPT, a brief typology of models is attempted here.

Mental Models are used to make daily decisions. They are often based upon an informal, undocumented mix of experience, bias, and environment. Mental models are often expressed verbally and, indeed, facility with word models (Jeffers, 1978) is a very useful rhetorical talent. These models are the precursors of other, more formal modeling attempts. These models differ from descriptions; they distinguish structure and process, and involve a logical, hierarchical problem-solving sequence (beginning with goals), which is similar to the protocol described for IPT. Mental models must be fairly simple because complex relationships become lost, particularly the feedback loops. Also, words often have more than one meaning and mental models can be vulnerable to misinterpretation.

Mathematical Models employ symbolic logic capable of dealing with complexity in a more objective, parsimonious, and less ambiguous

way than unrecorded words. Predictive statements are derived from clear rules for manipulating relationships. An example: carrying capacity for hoofed game is calculated by multiplying the forage available by its percent proper use, and then dividing the result by the forage required per animal multiplied by the length of their residency. These predictions can be tested against reality using the scientific method as described earlier, and validation techniques discussed in Chapter 6. The precision of a mathematical model allows it to be tested. The models described below are all mathematical.

Deterministic Models have predictable answers based upon mathematical relationships and calculations -- the values are completely determined because the mathematical terms, relationships, and calculations do not change. A point on a regression is an example.

Stochastic Models can reflect and accommodate the variability found in nature, where values can vary in unpredictable ways. The values are therefore chosen randomly according to likely probability distributions for the phenomenon being evaluated, e.g., from a binary, normal, or Poisson distribution of observations. Climate, biogeographical events (such as dispersal) and other important model elements can vary.

Analytical Models employ explicit formulas to derive predicted values, for example, regressions of weight (dependent variable)

on age (independent variable). Statistical and deterministic models tend to be analytic models.

Simulation Models are designed as an algorithm or procession of calculations to represent a dynamic system. The step-by-step solution of equations from an initial state to a future state is the process of simulation, and the representation of the systems in equations derived from the flow diagrams is the simulation model. Simulation models use equations which are interdependent, with the values changing through the solution of simultaneous differential equations, or by adding or subtracting from levels or variables during every discrete time step (difference equations). Simulation models can best reflect real world interactions of stocks and flows (levels and rates), and tend to be easier for the non-mathematician to understand than other mathematical modeling approaches. They also tend to be more difficult to fit to empirical evidence (Jeffers, 1978).

Dynamic Models show the behavior of variables over time. Examples are the number of wild animals over thirty years, or the net present value of an investment over the life of a project. Dynamic models almost always feature feedbacks (causal loops, servo-mechanisms, etc.) which result in explicable behaviors (e.g., explosive growth and declines to extinction, or, alternatively, equilibrium from negative feedbacks). Dynamic models contrast with static representations of a phenomenon or a

system such as a highway map or the regression of litter size on nutritional levels.

Spatial Modeling is a relatively new field and has enjoyed rapid development, paralleling developments in remote sensing, resource inventory requirements and techniques, geographic information systems, and computer hardware and software development. Berwick (1984) describes several applications in identifying the region of influence of a proposed project on the natural resources in its "neighborhood". Predicting the location of poorly inventoried, but significant biological resources, is another use of great interest in development (Nisbet et al., 1982).

Hybrid Models from the marriage of these various techniques will ultimately be the most significant developments in modeling. Some of the processes or variables described in a dynamic simulation model show transitions to other states. Bazykin (1974, cited in Holling, 1978) shows several possible system responses to disturbance -- different states called phase portraits of system stability. A disturbance such as overgrazing can change the state of an ecosystem to a new equilibrium with new species mixes, productivity, stability, etc. It will not recover to the old stability region or equilibrium (West, pers. comm.; Noy-Meir, 1975). Holling (1978) describes several fisheries which exhibit what he calls the "mischievous nature" of state transitions. This might prove critical to understanding the changes in woodlands, elephants, and fire in East Africa

which are described in Chapter 4 (Norton-Griffiths, 1979), as well as the pastoral systems described by Ellis and Swift (1988).

The hybrid models must eventually reflect such consequences of unpredictable, nonlinear interactions and thresholds which are not intuitive or expected, and which defy existing tools of policy design and evaluation. Project-related impact assessments should examine the likelihood of such instabilities through simulation models which incorporate probability. A single type of model could not explain or help manage these systems, and more than one type of model was required.

2.8.3 Can We Trust Models? If Not, Can We Use Them?

In an earlier discussion of the scientific method, we asked how we could be confident that we know what we say we know. The method and statistical tests, if properly employed, can tell us just how much confidence can be put in an answer. For example, nineteen times out of twenty (95%) we may believe a result based upon the variability of recorded observations.

However, the use of models for insights into future system behavior employs recorded observations to predict the workings of a simplified and imperfect representation of a system. The model employs initial observations, or a mixture of initial observations from several studies, but from these initial empirically-observed data points all others are calculated and not measured. The use of data is therefore stretched far beyond

the common uses of most observations which seek to explain contemporary phenomena.

Three sources of potential errors exist which might confound interpretation, generate suspicion, and make model validation very important if it is to be of practical use:

- the reliability of the data collected;
- the structure of the model as an abridgement of the real system; and
- the reliability of system behavior projections.

These requirements for trustworthiness are greater for establishing a tool which is much more vulnerable, because of its uses in forecasting, than most other technical tools which resource planners use. Yet there is little agreement on how best to validate models. In fact, there is even a semantic disagreement over using the word validation, which implies truth. Some students of systems would suggest that we can only disprove or invalidate models and that a useful model is one which survives "invalidation."

The whole question of validity turns on the purpose of the model. If, for example, a rancher would like to predict the behavior of a system to assist in selecting between alternative management policies, the precise prediction of a value ten years hence is not required. Assessing the uses of precision, Richardson and Pugh (1987) recall Lewis Carroll's observation that a clock which never runs is more accurate (it is correct

twice a day) than one which loses a minute a day -- but it is less useful for keeping appointments. Forrester (1986) noted that simulation models and the process which generates them should not be judged against some magical perfection, but rather in comparison to the existing alternative planning methods which are being used. The question of whether a model improves our understanding and capabilities over mental models is more germane than the question of whether it is right. Ultimately, enhanced understanding should increase net income on the ranch as much as a specific prediction.

Since the future can never be proven, true validation is really not possible, but models can be invalidated. We can demonstrate flawed behavior. If the model is rigorously tested and its behavior is suitable for the problem and consistent with reality, increased confidence in its utility is warranted. Ultimately, the record will show if the predicted outcomes were consistently generated by policies suggested by the model. However, confidence in a model can be generated by other methods which are useful in the present. A number of these methods are demonstrated with the Range, Livestock, and Wildlife model discussed in the next chapters.

The structure of a model can evaluated by examining:

Mechanics. What is the behavior of a model on which extreme conditions are imposed?

Concepts. Checks on conceptual validity -- similar structures developed independently by different groups familiar with the same real system will enhance confidence.

Experiences. Based upon prior knowledge and experience, does the model behavior replicate the reference modes or differ in explicable ways? If so, it is more trustworthy.

Surprises. If unexpected, surprising ("counter-intuitive") behavior is suggested and is eventually observed, a powerful boost to the credibility of a model is given. Such disclosure of surprises is an asset in combating risk. Consistently long-term responses are generally much different than short-term behaviors in a system rich in feedback. It has been observed that institutions tend to reflect either long-term or short-term perspectives, but rarely both. People also have long-term or short-term views of their environment or that of the organization.

Validity. Finally, the behavior can be tested against the measured behavior of a real system -- predicting history. It is difficult to find a good data set -- one with a sufficient range of variables measured over a long enough time period (in terms of the time boundaries and time steps of the model) to divide the run into segments, perhaps halves. The first half is used to observe the fit of model behavior against observed behavior. The Range, Livestock, and Wildlife model was validated in this way (See Chapter 6). The model is initialized with real data --

first year values for the actual system -- and then it is run. Discrepancies in the behavior of the measured (real) system and the simulation should be investigated (if they exist), explained, and the model reformulated to produce a better fit. This is a revealing process to improve the model (if it is reasonable enough to be improved) and understand the system. The process is called calibration. The actual data for the last half of the run are not even read or plotted until the model is tuned, and has simulated the full range of years of the entire data set. Only then are the actual observations of the last half revealed and the behavior of the simulation compared with empirical observations of the real system -- predicting history! The credibility and utility of the tool which has been created can then be determined. Statistical comparisons can be made to assess the degree of departure, similarity, and confidence. Can the inevitable quantitative discrepancies be endured if qualitative behavior addresses the key questions? Do simpler or different kinds of models yield better comparisons?

One caveat is the obvious lack of a known relationship between correlation and causality. However, if the last half of a simulation corresponds with the actual data, confidence in the model is greatly enhanced, particularly if some of the behavior is complex. Credibility is further enhanced if a compatible reaction to a significant and unexpected mid-run difference (such as a severe drought) is generated by the model. If a model which is rich in feedback and process shows agreement with the observed

system, it is less likely to be accidental than would be agreement from a deterministic, simple model.

Chapter 3

DEVELOPING AND USING AN INTEGRATED PLANNING TECHNOLOGY

		Page
3.1	IPT as an Analogue of the Scientific Method	93
	3.1.2 Analogues of the Scientific Method in Planning	98
3.2	Users' Needs	103
3.3	The Workshop	109
	3.3.1 Goals	109
	3.3.2 Workshop Participants	113
	3.3.3 The Protocol	114
	3.3.4 Workshop Requirements: Facilitators and Logistics	123
3.4	Post-Workshop Computer Simulation	125
	3.4.1 Model Development -- Flow Diagram	125
	3.4.2 Data	129
	3.4.3 Wooded Development -- Encoding	139
	3.4.4 Model Development -- Compiling, Debugging, & Testing	144
	3.4.5 Sensitivity Analysis	148
	3.4.6 Model Development -- Requirements	149

3.1 IPT as an Analogue of the Scientific Method

Baker and Allen (1977) pose the interesting question: how do we know what we know? A responsible planner (of anything) must know as much as possible about the area or system being developed. The planner must have access to information about the subject, and an indication of the confidence which can be placed in that information. Such trust turns upon how the information was derived, and the bias brought to its interpretation and use.

There are two broad distinctions in the use of information: mechanical application (sometimes seen in primitive and traditional resource uses), or understanding and use of processes and causality. Although the former approach can work quite well, the latter is important in directing an intervention or outcome for a system, particularly since individual "facts" and "truths" evolve and change. A so-called fact can change, for example, as natural systems are studied and more becomes known about them. Science is a process of developing insights by collecting and using information generally related to the insights. The application of these systematically derived insights is a goal of the applied sciences, such as agriculture or wildlife management. Furthermore, such a manipulation of natural systems toward goals implies a concern for the future (such as maximum corn production by the end of the growing season). Science has long struggled with prediction and other risk-related behavior.

Approaching science as a process requires participation by the student (planners, researchers, or any judicious users of facts) with a process commonly described as the scientific method. Using this method in solving problems enhances our confidence in an uncertain -- and sometimes devious -- world. The approach required by this method is not only useful in managing natural systems, but also to question current facts and dogma. At some point, both forms of technical progress require the employment of the scientific method, which is problem solving in the most logical possible way. The four steps of the scientific method are generally considered to be observation, hypothesis, experimentation, and communication. Having a method does not constrain initial insights, but helps to foster them. The biologist Szent-Gyorgi noted that the best scientists see what others may have seen, but aided by the scientific method, think what no one else has thought.

The foundation and initial step of scientific thinking is accurate, objective observation. These often undirected observations give rise to an idea -- maybe an explanation about the way things work. The observation process should minimize observer bias and employ the accumulated technical knowledge of the observer and the observer's predecessors. A requirement of the process which enhances confidence in the observations is that the observations (data acquisition) are repeatable.

Imagination, creativity, prior knowledge, and observation then interact to suggest explanations for observed phenomena. The untested explanations for the observed phenomena are called hypotheses. A hypothesis is formulated through inductive reasoning. Induction employs a number of specific observations which are summarized to formulate a general synthetic and predictive explanatory statement about the observations -- a hypothesis.

The hypothesis must be tested, often by an experiment. Experiments attempt to test the validity and utility of prediction(s) embodied in the hypothesis. Hypotheses are tested using deductive logic. The deductive syllogism employs the familiar "if...then" progression from a general hypothesis to a specific statement of predicted truth which must clearly follow. Deductive reasoning is the heart of mathematics, and mathematicians can conveniently manipulate symbols to prove (or more correctly, disprove) a hypothesis. Natural systems cannot be manipulated with such facility, and research to test hypotheses must therefore rely heavily upon experimental design and statistical analysis of the variance and confidence in the results.

Inductive reasoning is a method for discovery. Deductive reasoning is a method of verification. How does this immodest review of the epistemology of science bear upon the issues at hand -- renewable resource development planning and the uses of IPT? One model of program development generally employs the scientific method because it is useful in the logical development of programs and projects (See Figure 3-1).

Although both inductive and deductive reasoning have important roles in research and development, the observation and 88experimentation required for inductive reasoning can be time consuming and demanding of expertise and money. These elements are often short-circuited in favor of action.

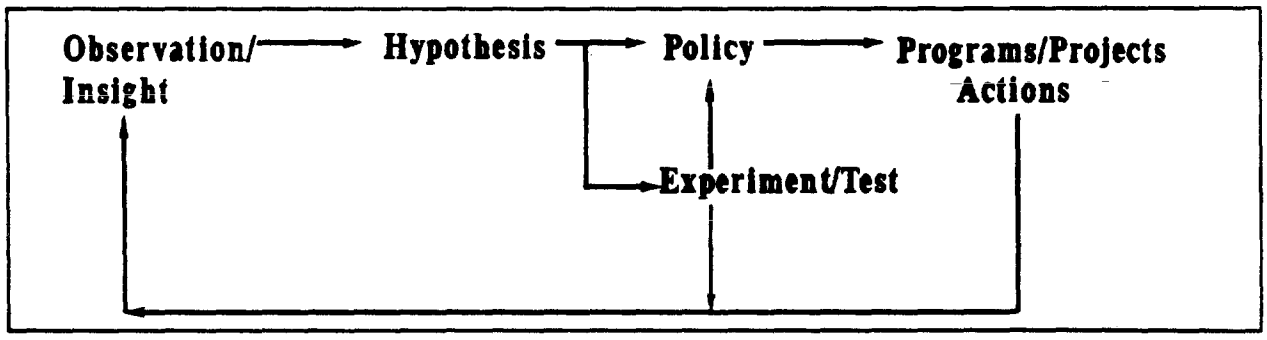


Figure 3-1. Elements of policy and program formulation. The idealized planning process depicts the iterative (inner loop) enhancement of hypotheses (including predictions) to the point where confidence generates a policy. The actions effect a change in state or environmental modifications which leads to new observations (outer loop).

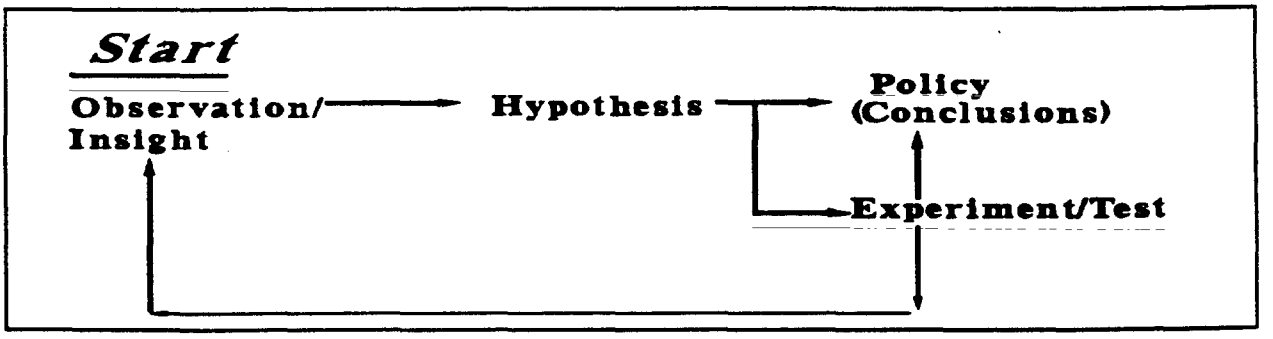


Figure 3-2. The inductive loop begins with initial observations and insights. Elements of inductive reasoning in planning proceed from a number of observations to a credible synthetic theory explaining the phenomena observed -- a policy. An example statement: "People are hungry. Food can be grown with the application of a limiting mineral. Therefore fertilizers should result in higher crop yields and human nutrition will be enhanced. Government should foster intensified agriculture (fertilizer, tenure, conversion, etc.)." An important goal of inductive reasoning is understanding.

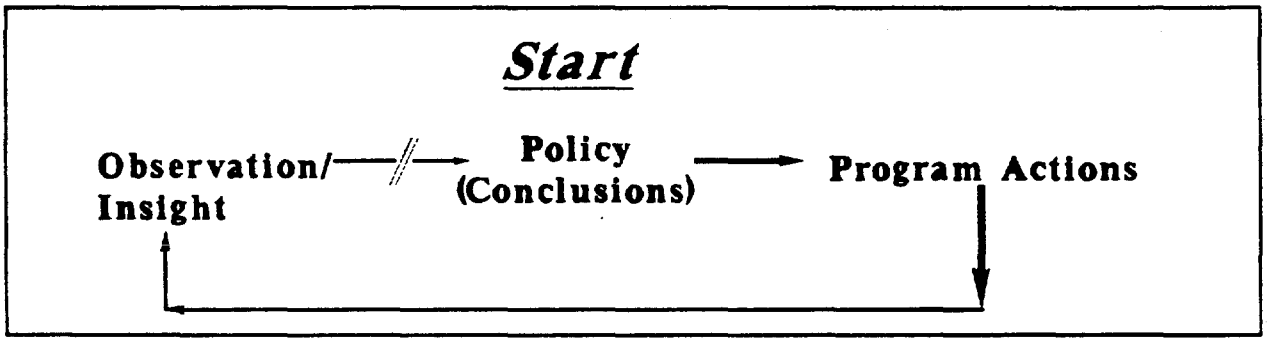


Figure 3-3. Elements of deductive reasoning in planning which proceed from the general (policy conclusions expressed in programs, for example, a sector strategy) to the specific observations. An example of a deductive statement: "If we intensify agriculture, agricultural amendments will be transported downstream which will poison fish. Fish are a major source of protein. Intensive agriculture leads to malnutrition." Therefore, the policy of agricultural intensification has generated a prediction (which shows some of the danger of deduction) through deductive logic. An important goal of deductive reasoning is action.

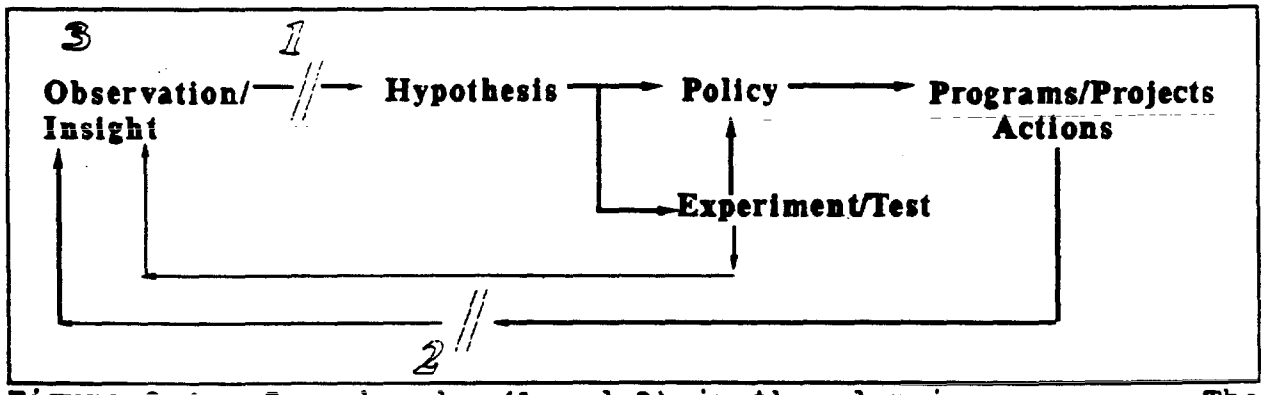


Figure 3-4. Some breaks (1 and 2) in the planning process. The planning process has regularly exhibited three weak points.

3.1.2 Analogues of the Scientific Method in Planning

Figures 3-2 and 3-3 display the elements of inductive and deductive reasoning embodied in the planning process. Where might planning errors occur in the idealized picture of Figure 3-1? Clearly, action without understanding (i.e., deduction without induction) is dangerous. Understanding without action can be trivial. Fig. 3-4 suggests some short cuts which occur in the planning process from time to time. The planning process has exhibited three weak points:

- The absence of keen, creative observers at the outset. Without such talents, activities are either reactive (fire-fighting) or inertial repetition of past action(s) (bandwagon).

- Skipping hypotheses testing and refinement (No. 1 in Figure 3-4) in the serene assurance that the observer knows enough to leap directly from an insight to policy conclusions. Variations on this short-cut can include consultation only within a like-minded group. The feedback afforded by hypothesis testing is eliminated.

- Failure to realize or incorporate the effects of an altered environment (No. 2 in Figure 3-4), which results from program implementation. Again, feedback is missing. Often, Nos. 1 and 2 occur, and planning is open-system, a common fatal flaw.

Depending upon the user, IPT can begin at one of two points in Figure 3-1. Each point coincides with a particular type of participant in development planning, either a development planner or a research scientist.

Development planners begin the IPT workshop by emphasizing the goals and issues which attend their development schemes -- the Programs/Action Plans point in Figure 3-1. The workshop protocol then asks them to characterize the system they presume to affect -- which observations are important and intriguing? In this way, IPT assists in closing a loop, squeezing out evaluations of the past and present by examining existing or historic issues, constraints, and problems. IPT becomes a tool in the deductive processes of development planning. It's ultimate contribution is to test alternative policies.

The use of IPT generates an additional potential source of feedback not otherwise available to the planner -- new insights from policy tests of the system model. This new feedback source is not depicted in the figures. Currently, development assistance policies are tested in real time with actual experience -- a long and costly process, sometimes aborted because of policy changes during implementation. The test of a well-considered policy generated by the planning process described in Figure 3-1 can bridge a career, or at least many assignments. Feedback is therefore difficult. A contribution of

IPT is policy testing by using models. These indoor tests permit a feedback path to be drawn between Policy (Conclusions) and Observations/Insights in weeks or months rather than years (See Figure 3-1).

The second type of user is the applied research scientist who begins with observations and insights, moving to system characterization and hypotheses. The use of simulation models to test and clarify scientific hypotheses is perhaps more common than for testing policies. System dynamics may be an exception, because of features generated by early uses which linked "quantitative" with "subjective" disciplines and information important to assess policy. IPT can be very helpful in testing hypotheses and employing inductive reasoning. However, IPT is less important to scientific research than to development assistance. Scientific experimentation and hypothesis testing can often be conducted in the lab or field at bearable costs -- including human. There is often no substitute for the test(s), and trial and error risk classification is built into the process. However, such interaction with the test, tuning and tinkering with it, is rarely possible if a large, complex development is the test, and it has already begun. Policy testing in development is really only possible with techniques such as simulation modeling. Perhaps IPT's highest use is to assist the development planner in incorporating feedback and deductive reasoning in an analogue of the scientific method, which reduces some of the historic risks and flaws of planning.

How does IPT employ the logic of the scientific method to explain observations in a useful way? What is the analogy to the scientific method? The IPT workshop protocol produces a system structure in the form of flow diagrams depicting the relationships between the variables and parameters. These processes, the boundaries which limit them, and the elements which are embodied in the structure, are all explicit representations of the system details. The elements and processes (system "structure") also represent the collective knowledge and assumptions of workshop participants -- their mental models. The elements and processes constitute their hypotheses -- informed, but possibly imperfect views of a specific natural system. Using, testing, and validating the model against historic, empirical behavior are the experiments which test the hypotheses.

These can be research hypotheses about system functioning or policy hypotheses emphasizing system management. The predictions derived from hypotheses about the modeled system can be found in the reference modes of predicted behaviors of important variables ("goal variables") sketched by model designers and users during the workshop. These predictions are compared with results generated by the model runs for the goal variables defined as important by users. For example, "If more rain results in more forage, and if more forage produces more cattle, then more rain will eventually result in more cattle" -- a deductive syllogism.

Workshop participants are asked to draw a curve of cattle densities as a function of different amounts of precipitation. This will be a reference, or control, against which the same behavior generated by the model will be compared.

3.2 Users' Needs

One fundamental flaw in developing a systems approach to analyze and formulate natural resource management policies was the attempt to use the inductive approach of research scientists and their models from academic settings. This common method of systems modeling most often generated mathematical models created in relative isolation by technical people, who at best had sporadic sessions with system developers and managers. The end users (e.g. farmers and ranchers) rarely helped build the model, knew little of its structure, and could therefore not assist during the evaluation of the model. A critical review was not available from those with empirical knowledge of the system. One of the most evident results of this model building method was a lack of ownership and understanding by users and others most affected by the development. The analysts and programmers offered the answers and a "trust me" approach.

Holdgate (1978) contends that "because of uncertainties, environmental science can be used to guide the development and management of natural resources only if there is a continuing interaction between the scientist and the manager. Dialogue is needed at the outset to identify the key questions posed by a new development -- such dialogue guides field study, analysis and modeling -- the building of the model is an integral part of the study, for it helps to structure the processes of both sampling and evaluation." Holling (1978) describes one such process

called Adaptive Environmental Assessment, a progenitor of IPT. He describes his group's "... bias that process and product are inextricably linked; the sequence and design of workshops -- and -- different modes of communication are as important as models and the analysis."

IPT is predicated on the conviction that systems analysis will never be embraced as a widespread policy planning tool unless the goals, issues, and system are defined by the users in a simple, efficient process. Both Holdgate and Holling are referring to such a process. The users (not imported modelers or managers) must help define their own needs, and with initial assistance, answer their own questions. They must understand the products and options generated by the method and understand the limitations of the method. They must know how best to incorporate IPT into the spectrum of other methods for solving problems and addressing development issues. The method must feature involvement, which will require relative simplicity, availability, realism, flexibility, and accountability.

Simplicity is afforded primarily by the model itself. The logic of the IPT modeling method (as with the scientific method) fosters and enhances the simplest, most understandable process of model development and analysis. The process proceeds almost inevitably, in a logical progression through the workshop protocol. Systems analysis fosters understanding the linked processes of the system, and provides a structure to help

categorize information and phenomena. The model must be simple enough for a user to trace through it's structure and explain unexpected behavior. In fact, this requirement is what sets the upper limit on model size and complexity. If it is too complicated to explain the behavior, it is too big. Therefore, we must employ simple models which render analysis more affordable or socially acceptable.

This combination of logic, structure, and thrift reveals a more tractable and simpler representation of a potentially infinitely complex world to people familiar with the system. The parsimonious structure fosters organization, recall, and understanding as well as later modifications. Furthermore, once the model is built and running to satisfaction, it can be pared down to its most basic elements -- just those necessary to retain its behavior. This reduction is done through a sensitivity analysis of the model to its different feedback loops, variables, and parameters. Those which have little influence on model behavior are excised.

Availability and access to any technology such as IPT turn upon local acquisition. A particular challenge confronts those who would presume to make it internationally accessible. The presumption is that common need and the logic of the approach will transcend the geographical and cultural distances between end users and the IPT developers. However, a strategy for access includes wide publication, dissemination through the USAID

Missions, use of existing central training programs at AID and other donors, and continued response to educational, research and development centers such as the Asian Institute of Technology and the Wildlife Institute of India. It is important that continued validation be conducted on new and evolving models. Most important, now that an initial development and validation has been achieved, the process should be increasingly used in the field and benefit from regular evaluations.

Realism is derived from technical credibility of the structure, reflection of first-hand insights about a specific place, decisions about what to exclude, and the data used. This requirement virtually dictates the user workshop feature of IPT, but also requires the contributions of knowledgeable scientists.

Adaptability and **flexibility** are important requirements for development planners. Development proceeds with a large dose of uncertainty -- for example, uncertainty about the data upon which the development strategy is predicated. However, development will no doubt continue apace whether data are available or not. For example, soil analyses for the Mahaweli Project upon which forecasts of best land uses and rice production were based, were largely erroneous (C. Anthold, pers. comm.). There is also political uncertainty, climatic uncertainty, market uncertainty -- the list is long. Uncertainty cannot be eliminated, but can be reduced and accommodated with an objective, flexible, and inclusive planning process. IPT is

designed to enhance flexibility at the outset, and embody the best collective understanding of a system through its reliance on the perspectives of users, managers, and scientists offered in the structured workshops. It is the antithesis of one modeler's limited perceptions (the "renaissance modeler"). The system's structure and model software are easily adapted as additional insights and understanding suggest changes through the implementation phases (See Figure 3-1). Data requirements are identified and prioritized and available data ranked for quality so that key information can be secured or suspected. IPT focuses upon testing different alternatives -- policies, data, and project configurations. An evaluation of plausible alternatives is useful should they arise as considerations.

Finally, **accountability** and the depiction of design rationale through text and graphics is a feature of IPT. Since many projects have planning horizons which outlive key participants in the planning process, it is important to know why (or even what) decisions were made to structure a development policy and project. The Mahaweli Project was planned over two decades by several independent donors and numerous consultants. Some development efforts go into a holding pattern between planning and implementation during which time conditions may change. We encounter gaps in institutional memories which impede redesign or adaptation to feedback. Flow charts with descriptions and accompanying data and assumptions preserve a clear picture of planning at a specific time in the project life.

If these features of IPT had co-evolved with system dynamics, it is likely that system dynamics would enjoy much wider application than it does. Historically, system dynamics has been applied to industrial management problems (Forrester 1961; Roberts 1977, 1980), urban planning (Forrester, 1969), global resources and carrying capacity (Meadows et al., 1972), and a host of other issues from law to ecology. Unfortunately although the development and uses have been innovative and often brilliant, active use of system dynamics has remained in very few centers driven by a few talented individuals. This has generated uses with only rare validation. System dynamics also exhibits an inbred literature which cites itself too often to break out of a few regional groups to the universal applications which require such a useful tool. A very thoughtful review of the history, uses, and shortcomings of system dynamics is given by Meadows (1980).

3.3 The Workshop

3.3.1 Goals

IPT employs a workshop of knowledgeable contributors (experts) and eventual users to define a system and the issues which surround its management toward certain goals. IPT workshops are designed to produce an objective and graphic representation of a natural system. This model should be the simplest representation of a system which can incorporate and address the problems which users have. The users often are managers of the system. Integrating the elements is the primary focus of the workshop and is necessary to understand and plan for the development or preservation of that system. These elements are the measurable variables which define a particular system. They can be cattle numbers, net profit, amount of water infiltrating into the soil, soil eroded, or other such variables. Variables can be a measurable quantity or a rate which feeds (input) that quantity, or drains (output) the level. The first assumption is that conventional planning unrealistically segregates these elements, and therefore has not worked well. Producing a graphic representation of a system's structure created by a knowledgeable group yields the basic product of the workshop -- a conceptual model specifically conceived to address certain issues. The mutual education of participants about important system elements and processes is another valuable product of the IPT workshop. The conceptual model may also be the precursor of a simulation model.

A second assumption is that experienced people are very good at constructing a reasonable representation of very complex systems, but have an extremely difficult time assessing more than the most direct and obvious consequences of a system intervention. People are better at structure than process. The interactions, such as the second- and third-order ripple effects which feed back and through linked variables and processes, are difficult or impossible to anticipate, particularly in ways useful to a manager such as timing, quantities, or relative magnitude. We have difficulty predicting changes in a two- or three-variable system, yet the typical systems of hundreds of elements which emerge from the workshops are those which must be addressed in the real world. We therefore use the workshops to define problems and systems which will later be manipulated by the computer if the issue warrants a computer simulation for policy testing.

Through the device of a relatively public workshop attended by people with a variety of skills, interests, and experience, we hope to minimize the biases and value-laden agendas which might influence goal, problem, and system definition. In addition to minimizing bias, we hope to maximize objectivity, auditability, and credibility. These concerns simply admit to human capabilities and weaknesses. The IPT process attempts to account for our limitations, just as sampling design and statistical tests do. Another goal of the IPT workshop is to convey a sense

of participation in constructing the product. The interactive aspects built into the IPT workshops confer a sense of ownership in the products which is notably missing in those who miss or abridge their involvement in the workshop. This is significant because skepticism and apprehension about the process and products (generally not the need, however) are inversely related to participation in the workshop (See Figure 3-5).

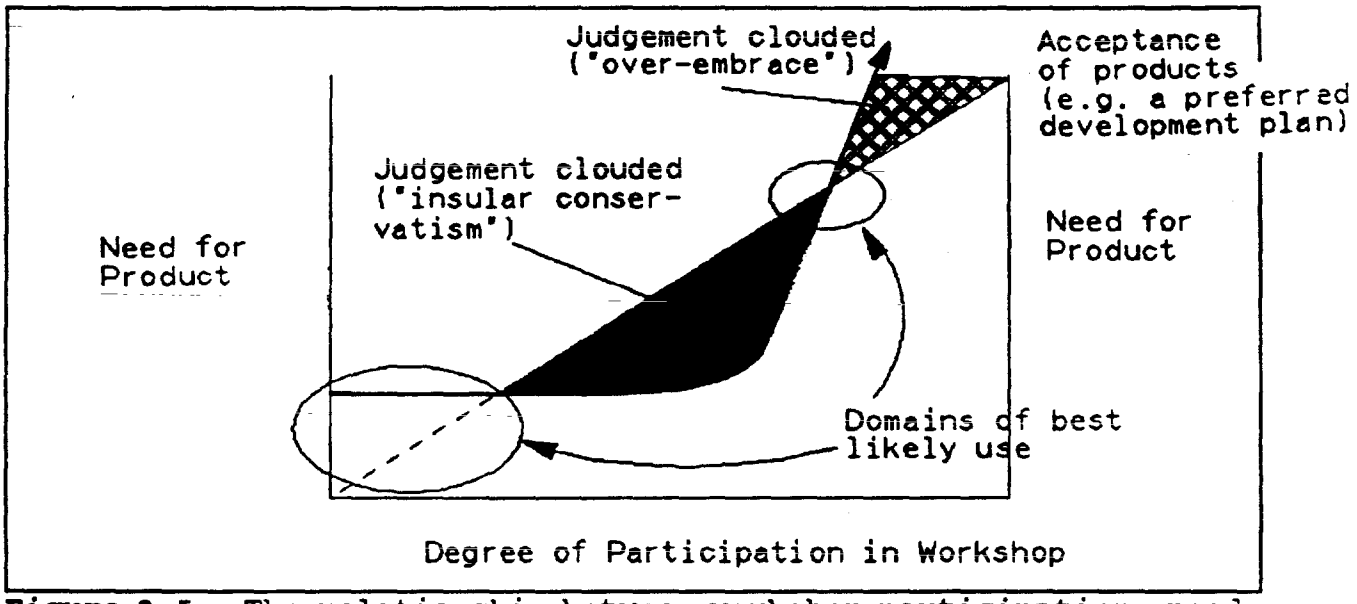


Figure 3-5. The relationship between workshop participation, need, and product acceptance.

Acceptance is related to both need and workshop attendance and participation. The slopes of need and acceptance are not the same -- a certain degree of need will generate a certain amount of acceptance -- even without workshop attendance (See Figure 3-5). This was the case at Negros Island in the Philippines, where a rational planning tool such as IPT was accepted without

adequate local participation in the process because of the desperate situation: land-use conflicts, malnutrition, and insurrection. Two areas of Figure 3-5 indicate the maximum likely appropriate use of IPT products. Where there is no immediate need, user interests and curiosity allow some dabbling, and time constraints and the stress of a deteriorating operation do not dominate, then rational interpretation and use of IPT products are more likely. Likewise, the best uses are likely to occur where increased need has captured and focused the attention of the user, but has not yet reached the point of desperation.

The IPT workshop is designed to produce a graphic representation of the system on paper, with its elements, links, feedback, and boundaries. The paper copy is primarily lists of goals, problems, key questions, assumptions, as well as the flow diagrams of the system (See Figures 5-6 through 5-32). These diagrams depict the minimal set of elements and relationships useful to answer the key questions, which in turn address problems frustrating the achievement of participants' goals. A vision of the products and their utility is essential to keep the workshop on target. Whether the flow diagrams are used to construct simulation models or just to clarify the problems, system, and links, this basic requirement of graphic workshop products is firm. Use of the protocol which is described in Section 3.3.3 ensures targeting and efficiency in extracting information from participants. Different workshops may have different foci, even when addressing biophysically similar

systems. A university research team may have a different set of goals than a development assistance planner. This is important because the goals are the initial inputs which determine the rest of the products.

3.3.2 Workshop Participants

Just as a host is careful to construct invitation and seating lists for a dinner party, the conveners and facilitators of an IPT workshop must take care to ensure representation of required expertise and those who will actively and productively participate. The organizers of a workshop are driven by the knowledge that all insights and eventual uses will ultimately be at the pleasure of the participants (who are the clients).

Capturing participants' expertise and experience is predicated upon finding the right participants. An honest effort to reflect the realities of the system, its users, and occupants will dictate the workshop participant list. In the Range, Livestock, and Wildlife model, we have enjoyed the participation of veterinarians, range scientists, animal scientists, agricultural scientists, wildlife ecologists, economists, ranchers, systems analysts, government planners, non-governmental organization principals, professional hunters, and others. Every workshop in which the authors have participated has been productive and fun -- possibly because the process was engaging and enjoyable. However, we know of other instances (described

below in 3.3.4) when this was not the case, participants left early, and goals were not achieved.

3.3.3 The Protocol

The workshop proceeds through a protocol which sequentially identifies and develops the goals, problems, key questions, variables, boundaries, reference modes, and structure. Generally participants are impatient to depict the structure, which generates a fascinating interplay of ideas, and fulfills the pre-workshop image of what modeling is all about. However, without slogging through the initial steps needed to focus the structure, few useful insights can be produced. The protocol is discussed now, although its use in an actual workshop and the products it generated are described in Chapter 5.

Goals. Profit enhancement is one example of a goal. Planning for such a complex and partially understood system as a river basin, or game and cattle ranch requires an efficient and focused definition of the goals of the endeavor. Our first workshop five years ago addressed the Mahaweli River Basin development scheme in Sri Lanka. The specific goals of the project included, for example, irrigating 117,000 hectares, resettling 500,000 people, producing 550,000 tons of food annually, and maintaining existing natural resource systems (TAMS, 1980). The goals of a later workshop (to produce the model validation described in Chapter 6) reflected the desires of the ranchers of Chiredzi, Zimbabwe to make a profit, satisfy local meat demands and therefore enhance

relations with indigenous neighbors, access the appropriate production technologies which are unknown or unavailable to them, and maintain maximum biological diversity and sustainability.

Problems. The inaccessibility and slow development of required infrastructure for both the Mahaweli and Chiredzi cases are examples of problems which frustrated the achievement of goals. Hospitals, schools, and farm-to-market transport could not keep up with in-migration at the rates planned in the Mahaweli. Securing foreign currency and the foreign-made goods required for operations, impeded the Chiredzi ranchers.

Precisely defining issues is eventually important to focus and structure a potentially unwieldy model in order to address a discrete set of questions. Without focus the desired policies cannot be tested and the right questions can't be answered. Without the protocol, issues of personal concern can subsume some corporate or project-related issues. Rarely is care taken to objectively define the real issues (among, typically, many shadow issues) which attend a development goal. The process is designed to foster enhanced efficiency through enhanced focus.

The issues appropriate for IPT applications can be partially classified by the point in the IPT process reached when the process is terminated. Many problems can be usefully addressed in the workshop, but the process is terminated before any simulation model is built. It is estimated that 45 percent of

the understanding of a system which occurs through the system dynamics process can be gleaned at the workshop before any computer use. Another 45 percent occurs during encoding and debugging, and 10 percent of the new knowledge of a system comes from computer-assisted policy testing of the model. The workshop-generated products are useful for dealing with most problems (See Figure 3-6) and the process may terminate at its conclusion. The subsequent activities and requirements may differ depending on where the IPT process is terminated. For example, simulation modeling to evaluate the impacts of alternative policies will require data, but building a conceptual model in a workshop may not require data. A simulation model will require site familiarity, but a conceptual model may not (depending on its scope and purpose).

Clearly the structure of Figure 3-6 can apply to many problems which could benefit from IPT, not just exclusively natural resources. Therefore the appropriate problem is very much a reflection of the interests, competence, and mandate of the users and facilitators. An *a priori* taxonomy of uses cannot be divined, although some productive kinds of applications for IPT were described in Chapter 1.

Key Questions. Major problems must be addressed by asking key questions. For example, to clarify or resolve the issue of carrying capacity, a question might address the degree of

competition for forage between domestic stock and wild grazers. These are the questions which the model must be able to answer. Posing key questions guides efficient model development. For the Mahaweli, a few of the key questions posed by the group were: Will crop production targets be achieved and sustained? Is sufficient energy available for the population anticipated over the life of the project? Will population growth exceed carrying capacity with respect to infrastructure and natural resources? Examples of key questions which were defined by the Chiredzi ranchers included: Where will the break-even point of a given investment occur? Is it more profitable to change the mix of animals to suit the vegetation, or the vegetation to suit the animals? What kind of information is most important to achieving the goals?

Variables and Parameters. To answer key questions the model must incorporate a minimum set of variables and parameters. These elements are later linked in appropriate ways with various feedback loops. Necessary elements might include the number of wild grazers, their birth and death rates, or drought periods. With the goals and questions as a foundation, the more familiar and traditional tasks of model development begin.

Initially, the workshop participants decided which aspects of the project (a river basin development, or the management and development of a ranch) should be represented, and how. The system should initially be grouped by large categories called

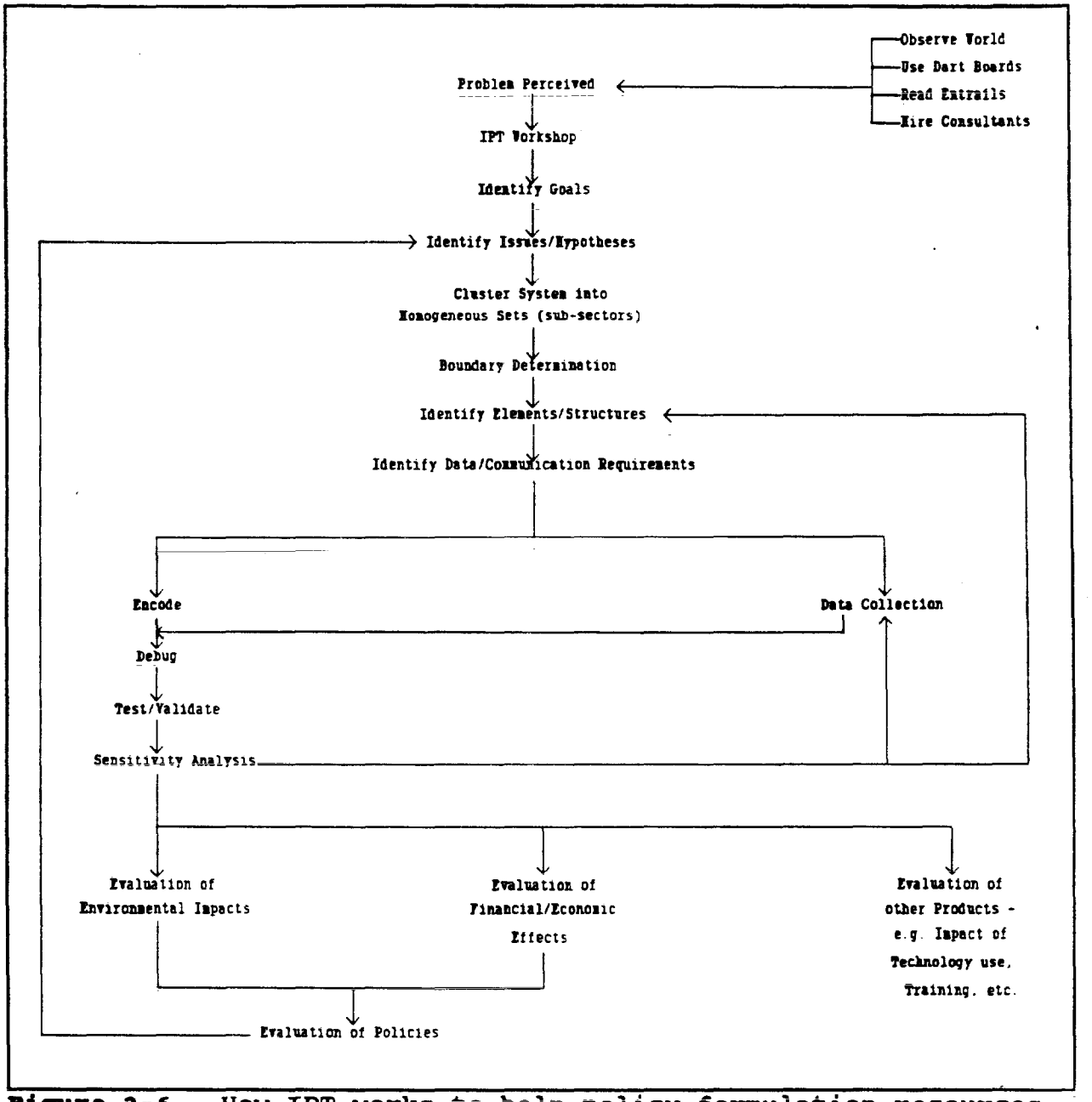


Figure 3-6. How IPT works to help policy formulation resources.

sectors or subsectors. This organization reflects the advantages of structuring information. These groupings are linked and are also somewhat arbitrary, but they are useful to help conceptually organize the system into familiar taxa, and also to divide the

work. The Mahaweli had agriculture, wildlife, forestry, socioeconomics, irrigation and water supply, and land use sectors. The Chiredzi Range, Livestock and Wildlife model embraced subsectors called livestock, wildlife, veld, and economics. If warranted by the number and interests of participants, each sectoral group represented at the IPT workshop can meet separately to develop their part of the system. The groups must eventually meet together to define specific links between each group, assisted by a rapporteur for each group. This was the approach taken during the Mahaweli workshop when each rapporteur described the model developed in his or her group, while members from all of the other groups noted which of the specific variables linked to their own subsector variables. At Chiredzi the workshop was small enough to be conducted as a single group.

Boundaries. Temporal and spatial boundaries of the system are established, and could include a single ranch and two drought periods for the area, if such boundaries will permit the model to address the key questions.

Reference Modes. Reference modes are educated guesses about a system's behavior based upon mental models of the system. They are educated because the participants include scientists and those with local expertise -- often users of model outputs. Participants graph the expected behavior of system elements over time before they see any simulated behavior generated with the

assistance of a computer. A reference mode could graphically depict the anticipated forage production over a time period which embraces two droughts (e.g., twenty years). These sketches of the postulated behaviors of an important element -- called a goal variable -- mark the level of the participants' understanding prior to full development of the models. They are "references" or controls against which to compare the model behavior later generated with computer simulation runs.

As the model is developed, we ask what might be lacking in our understanding, in the model's structure, or in the data quality to account for the differences between our reference modes and model output. There are three possibilities: the reference modes could be wrong, the model could be wrong, or both. Figure 5-1 also illustrates the range of mental models for a single variable of the system or project within the group. There is no unanimous view of system outcomes, even among the most experienced participants and even with the simplest test models. We use such simple tests at the beginning of a workshop to demonstrate how experience or bias leads to many differing behavior estimates of the variables generated by our mental models. The need for an IPT-like tool to assist us in planning the development of much more complex real systems quickly becomes clear.

Structure. Using the steps in the protocol described above, the structure is schematically represented by flow diagrams of the

theories and concepts embodied in the model. Construction of flow diagrams is the last step in the workshop agenda. The flow diagram is built from the elements defined by the group. Diagraming proceeds one step at a time, one variable at a time. The basic stocks (levels) and flows (rates) are identified, as well as the auxiliary variables which elaborate each rate. A stock might be the number of small wild browsing animals, an inflow rate might be births, and two auxiliaries which influence the realized birth rate might be nutrition and illness. These auxiliaries might be further broken down, before data are gathered for them. Particular care is taken to identify major feedback loops which will control the behavior of the system. To place IPT in context, an expanded discussion of models and modeling is given in Section 3.4.1. Examples of flow diagrams and their rationale are given in Chapter 5.

In keeping with the IPT tenet of user-construction, the existing depiction of a rangeland system and the community of human and animal populations it supports was derived during several IPT workshops in the United States (viz. USAID and several universities) and Africa (Botswana, Kenya, and Zimbabwe). In each instance, the system's structure has changed very little. The few changes tend to reflect essential, often unique characteristics of the site and of local, endemic issues. In other words, there appears to be a basic, common body of knowledge and perception of such a system and its components,

driven by a recurring core of problems. What is taught in range and wildlife ecology and management courses, or observed in the field, appears to reflect some general theory. The structure of the Range, Wildlife, and Livestock model has been rebuilt and confirmed repeatedly in different places by different groups. Each group begins with a clean slate, with little input from the IPT staff facilitator, yet winds up near the structure of other groups.

Furthermore, certain "generic" structures reappear in the description of most system processes. Richmond et al. (1987) describe seven such processes which characterize most process-generated behaviors exhibited by systems. One common example is "compounding", a process which feeds upon itself to produce such biological phenomena as exponential growth.

3.3.4 Workshop Requirements: Facilitators and Logistics

The workshop usually requires two days. It should ideally enjoy the participation of four to fifteen contributors representing a spectrum of user expertise and points of view, such as rancher, ecologist, veterinarian, anthropologist, range economist, and development specialist. Some participants (at least one, preferably more) must be very familiar with the site and situation in question. The IPT facilitator(s) must be experienced and able to evoke fruitful participation while avoiding the imposition of personal knowledge or opinion. The facilitator must also keep the goals and trajectory of the discussion in mind and act as a prod, scribe, ombudsman, and moderator.

One early IPT workshop involved sixty participants divided into nine sectors. Exceptionally complete and insightful coverage was generated by six of the groups. Although the remaining three groups were run by technically qualified scientists, the results were disappointing. A review and debriefing revealed that some technical competence was very useful. Knowledge provides insights useful to expand the considerations as well as to question the developing model and prod participants. However, it became clear at these workshops that technical competence alone is not sufficient to guide the protocol. Among the flaws encountered in the conduct of the three sectors (which had to be redone later) were:

- A deferential and submissive leader who could not keep the group on track or stick to the protocol. Unfortunately, this flaw was compounded by the dominance, knowledge, and enthusiasm of one very experienced and vocal participant who had a different agenda. Although the group leader knew system dynamics and the topic under consideration, he was bulldozed into changing the goals and tactics. The product was of interest to the leader of the coup, but useless to much of the structure being produced in the other groups. This became evident in the plenary sessions where links between system elements were identified.

- Lack of experience in conducting the workshops revealed how important such experience can be in achieving constant, timely progress to clear goals. This is particularly important in larger groups (more than four), with vocal and contentious participants who are usually the major contributors, but who also have the potential to deflect the discussion. Controlling without dominating, irritating, or constraining the participants who are generating the products is enhanced with some experience and natural flair.

3.4 Post-Workshop Computer Simulation

3.4.1 Model Development -- Flow Diagram

The requirements of the IPT process were described earlier (simplicity, availability, realism, flexibility, and accountability). Several of these qualities are also required for an IPT-generated simulation model. However, the simulation model, if it is desired as an additional product subsequent to the workshop, needs some additional definition. It must be a dynamic model because all systems change over time -- populations grow, businesses fail. Many of our planning tools provide static analyses and projections (such as a map, some regression analyses, linear programming, etc.) which do not facilitate dynamic planning. System dynamics models accumulate inflow and outflow rates in short time steps over a longer period. They integrate these changes in the variables by simulation. Furthermore, these changes are related to each other in cause-effect feedback loops, such as when room temperature is controlled by a thermostat, supply and demand interact, as do herbivores and their forage, predators and their prey. The dynamic behavior and system stability are determined by feedbacks and explicit or implicit system goals.

The possible modeling approaches useful to extend workshop products to a simulation model were considerably narrowed by the variety of modeling techniques available, the constraints imposed by the requirement to have the user define and design the model, and the need to model both subjective and quantitative

relationships. We chose the system dynamics method and the Dynamo computer simulation language for MS-DOS microcomputers to develop the model in this book. Other simulation languages for system dynamics models are available, such as STELLA for the Apple Macintosh (Richmond et al., 1987). Dynamo and STELLA are dynamic simulation languages because they show "level" (variable or element) over time (e.g. two drought periods or the life-of-project). The algorithm simulates by addition or subtraction to a countable quantity of the level (mathematically, integrates) such as number of cattle or kilos of forage. Quantities are iteratively calculated from simple equations (see below) over a defined time-step or "dT". This can be every six weeks for one version of the Range, Livestock, and Wildlife model. Therefore, each of the 300 or so equations generated by the workshop-derived model is calculated every six weeks for 30 years (about 260 times)! This is why the computer is used.

One feature of Dynamo and STELLA which makes them suitable for workshops, as well as for conferring the ability to graphically define dependant relationships, are their ability to graph tables. The lay user may be knowledgeable about the system, but is not likely to think in terms of equations to describe the curve of a relationship such as birth rate to nutritional state or growth over time. Workshop participants can draw the curve of a relationship (See Figure 3-7), and Dynamo then uses the table function to look up the encoded coordinates describing the curve on the x-y axes. With STELLA, the curve is

simply drawn with a mouse and the coordinates are automatically inferred! A picture is worth a thousand equations. It is much easier for most of us to draw a curve of a relationship than to depict that curve as an equation with three or more terms. Equations are particularly awkward to use as a communication medium in a workshop.

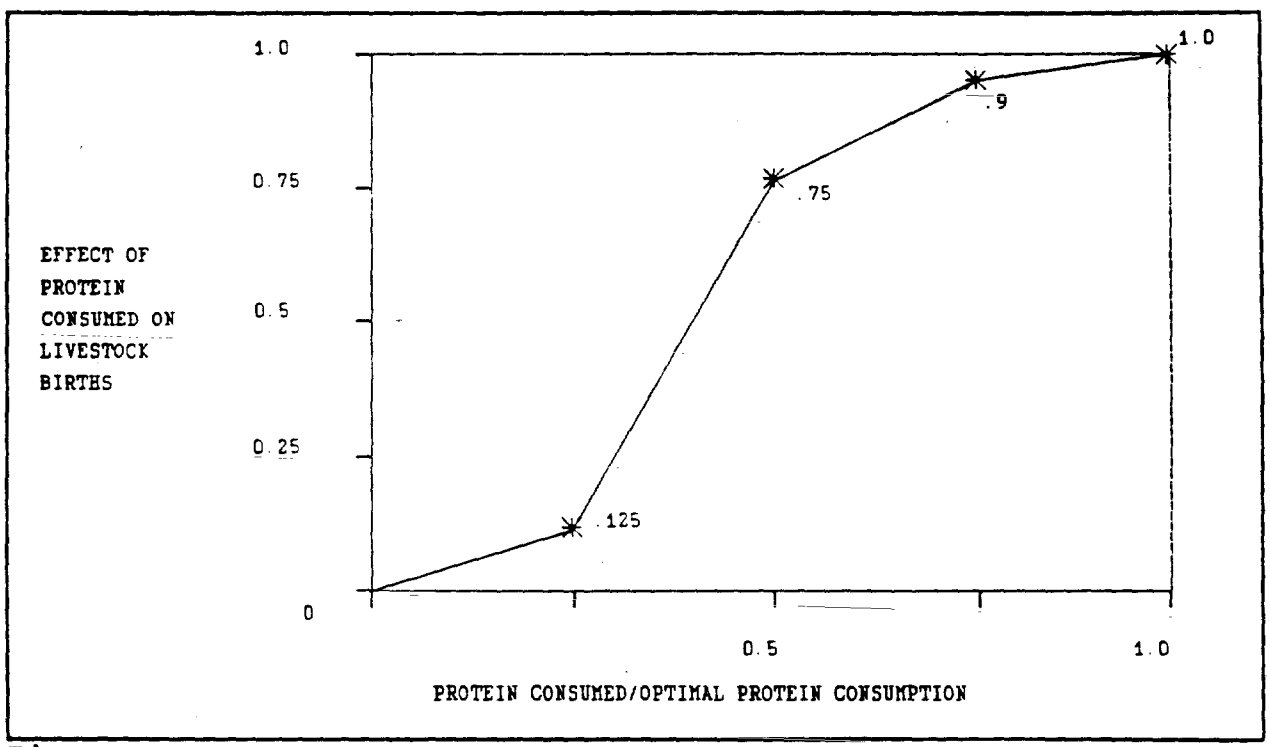


Figure 3-7.

Important facets of many systems describing the development environment are often fairly subjective. These can include social, economic, and cultural cause and effect relationships. For example, a feeling of equity and participation by residents of a project command area to successful agricultural extension efforts may be critical to the effectiveness of extension

programs. Extension may be critical to achieving project goals in agriculture, forestry, fisheries, or wildlife conservation. Such subjective relationships can be accommodated with Dynamo or STELLA tables as well. Experienced extension agents can graph these relationships. Later, sensitivity analysis can be used to determine the importance of the subjective variables.

The system dynamics approach and the Dynamo or STELLA software could, with accommodation and modification to the demands of development assistance, provide users with a reasonably accessible technical tool. IPT provides the modifications and environment for them to use these existing tools.

3.4.2 Data

One of the trickiest steps for the modeler comes just after the workshop. Processing the products of the workshop so that the coarse representation of the system which inevitably resembles a laundry list of variables, cause and effects, is transformed into a flow diagram which accurately reflects process and which is useful in writing equations, is a real intellectual challenge. The workshop will indicate the many feedback loops to be incorporated into the flow diagram -- the positive loops which generate boom growth or unrestrained decline, the negative loops conferring stability to the system. The challenge for the modeler at the post-workshop step is to envision the type of curve (behavior) a process can produce. These may include exponential growth of a stock, oscillations with increasing amplitude, convergence of a stock to a goal level, logistic growth to and asymptote, or seven other "curves" which represent about all of the processes which can be exhibited by a system. For example, an unrestrained population growth curve can be represented by a curve. Each of the eleven curve forms has a characteristic structure which is represented in the flow diagram. Each displays certain loops which will determine model behavior. A certain vision and experience is useful in this process of defining workshop products. Once a good flow diagram is produces, the equation writing is relatively straightforward. STELLA software actually uses the diagram drawing process to identify the logic for the modeler - i.e. suggest the equations.

This represents a systems way of viewing and representing the world. It is a way of thinking and problem solving. It is beautifully and fully described in Richmond et al. (1987).

Types of Data. Taking a conceptual model to the point of simulation capability requires reliable data for the constants, parameters, and initial values. Models are data demanding. Rarely does a model enjoy the use of data collected specifically for the model. Ideally, the data would be collected for the particular model and issues it is designed to address, as well as being appropriate for the site and time. The users would know how the data were collected and reduced. More often, the data collection uses products from other studies of related issues and sites. Sometimes data are so derivative and suspect that they are part of the negative aura which taints all models. The collection of useful data represents a qualitatively different set of activities than modeling -- even to the extent that it involves a different cast of scientists with different styles, agendas, and skills. Data can often be collected as afterthoughts to the model.

The data for the range, livestock, and wildlife model's elements are collected or selected from the existing Lotus data base. The data base now contains about 1,000 data points for the Range, Livestock, and Wildlife model. These data are put in to the model, which is then compiled, debugged, run (the simulation), and tested. The behavior of variables is critiqued.

In the situation described in this report, it was also validated against empirical observations as a credibility check. The model is then ready for policy testing. The post-workshop process can take several months, depending largely upon the existence of a useful model and the alterations required.

Data problems can become communications problems. We witnessed one expensive demonstration of a communications breakdown between modelers and data collectors and users. Over $2 million of Landsat imagery and analysis proved useless when the elegant clustering of spectral signatures into 26 colorful "types" had no meaning for analysts and data collectors who wanted a map of range vegetation and use for about 125,000 square kilometers. The modelers had produced an elegant, statistically valid, but useless product because the people with site knowledge did not have input at the beginning of the analysis.

The modeler-data collector dichotomy is not the only problem encountered while trying to construct a simulation model. Often the experience of the modeler or modeling team focuses on the careful collection of only certain kinds of data. A complex, multisectoral model may represent the wisdom and inputs of many disciplines represented at an IPT workshop. However, after the model construction crew departs, those remaining may tend to do best what they have done before. For example, collecting subjective but critical information from social scientists for a Dynamo table relationship may be sloppy (or overlooked) if there

is a focus on quantitative data. Such subjective information may be collected with a poll or Delphi-produced graph of, for example, the feeling of equity or participation on the part of project command area residents in making an extension program work. Soliciting information from those with experience becomes very important for this type of relationship, which is rarely measured.

The simulation models discussed here require two of the many kinds of information important in natural resource planning. Examples of the variety of information types include:

- spatial data (in Landsat's binary code for spectral signatures, or in habitat maps),
- bibliographic data (technical reference articles),
- registries (consultants for specific resource fields, cataloged museum specimens, endangered species, laws),
- graphic support (reference photographs of vegetation plots over time),
- processes described in text and graphics (flow diagrams, decision trees), and
- numeric data and thematic on-line data bases (electronic data bases accessed by computer and modem).

Simulation models typically require:

initial values for the beginning of the run (e.g., number of small wild browsers in 1950);

constants such as pi or unit conversion multipliers;

parameter values which are system specific, such as the maximum birth fraction of small wild browsers; and

tables, which define dependant relationships of one variable to another.

Data Collection and Evaluation. Skeptics of modeling as an appropriate approach to resource planning and research in the developing world will invariably focus on the data issue. The assumption is that useful data rarely exist. We have found that this is not an issue. The first IPT workshop four years ago began and was finished in a week. A very quick collection of necessary data yielded 90 percent of the required information, and the rest was supplied with educated assumptions. Technical experts know where to locate data. Modeling efforts since the Mahaweli workshop have employed skilled data collectors with more time. All the data points which the various IPT models require have been found. Data are not required for all 250 variables in the Range, Livestock, and Wildlife model but are required for initial values, constants, and tables. Many variables are calculated by the model, for example, rate variables such as births per year.

Collecting the necessary information is a chore requiring knowledge of a specific resource topic and its literature. It is important to know where to look and whom to ask. Another significant reason technical competence is essential in the data provision stage is that the data often require transformation to

units which the model can accept. These transformations can be mathematical (e.g., log or arc-sine), or involve aggregating raw values (e.g., using daily forage intake of impala, klipspringer, and duiker to get a weighted average of daily forage consumption by the level category "small wild browsers"). Of course experience in the applied sciences to which the data relate is useful to evaluate data quality and availability.

The real issues are data quality and portability. For IPT, an attempt to assess quality by crudely scoring data between 1 (poor, e.g., anecdotal), and 5 (good, e.g., in a refereed journal) has identified where the data may be weak. However, if a sensitivity analysis shows that the model element has little influence on model behavior, suspect data are of little concern, and increased collection efforts are probably not warranted. The element or loop may even be dropped from the model. If the element or process (feedback loop) has a significant effect (for example, in magnitude and its ramification through effects on distant variables) and data are suspect, some field inventory or research may be indicated. The process can distill and focus data collection requirements and help prioritize research.

A method such as IPT, which can identify and prioritize data requirements, can discover consistent, recurrent data requirements and suggest research in anticipation of specific, regularly occurring data needs. Data would then be available for project planning when such planning occurs. IPT can also clarify

the point in the project cycle when information must be provided to or received from other sectors as determined by linkages identified in the system workshops. These later data requirements are identified and sequenced in the collection effort, which makes their collection more likely. Many more useful, trustworthy sources of key information must be available when needed for planning to improve availability and data quality. This means much information can be collected in advance of a particular need.

Engineering problems and solutions can pose fundamentally different time constraints on planning than environmental questions. On an assessment familiar to the authors, the deadline for an initial project operating capability was dictated by a variety of political, strategic, economic, and other factors. This date was fixed. All of the planning, assessment, construction, and testing which would lead to this target date was planned by working back from the target date. Each task was assigned time, staff, money, and other resources. Tasks which had to begin and end on time because subsequent work depends upon them (i.e. on the critical path) have stringent requirements for timely provision of data. An endangered bird species migrated into the impact region in October, but the assessment report was due in August. An engineer can test rock for its specific gravity throughout the year. Project management could see no reason why more money and some overtime couldn't finish the analysis before August! Seasons have a fundamental influence on

the ability to collect biological (and sometimes physical) information, and on the kinds of information available. This is why most projects and planning models can accumulate a small amount of project and site-specific physical information, but often rely on the literature for many biological inputs.

Working Within an Imperfect Information Environment. Through its workshop, IPT indicates the information which is required to plan a project, and makes use of that information to test various development policies through a simulation model. Although the first part of the process, the workshop, culminates in a conceptual model of the system being developed, it does not require data. The information requirements in the early stages of IPT are perceptions, insights, and technical knowledge. The creative interaction of first-hand observations and technical knowledge fosters the appropriate picture of the system representation. Lack of information at the workshop is really a result of inexperience, deficient technical expertise, or a communication breakdown. It is not really due to a lack of data to set parameters for the model.

Once the workshop portion of the IPT process is finished, information requirements center around data. Data can be classified in various ways (See above, 3.4.1), but problems with information at this stage center on five characteristic information environments:

- Lack of data: spotty, suspect, or poor quality.

- Data at the wrong scale, for example, too aggregated, too short a time frame.
- Data from other sites.
- Too much data, too difficult to sort or access.
- Inability to use the data, for example, because of equipment limitations, embargoed information, knowledge limitations, communications breakdown.

The challenging information environments encountered in international development work can be addressed partly by a direct attack on the problem: collect good data, provide more training, or acquire a computer. However, the direct approach may not always be feasible. Many common recurring data needs suggests research in anticipation of specific needs for a project. A certain amount of information is generic, can be anticipated and be available on the shelf. The use of techniques to compensate for poor information are discussed in this book. Models, statistical tests, devising a common language to enhance communication, and employing a step-wise logical process can all help to improve a difficult information environment. IPT functions to provide such a tool. However, some limitations of an information-deficient environment may not be overcome. If assumptions, extrapolations, or judgments must be made to generate the information required by the simulation portions of the IPT process, they must be stated (as they should with any planning method).

If feasible, the results should be validated (See Chapter 6, Section 2.2). The uses and interpretations of the products of

casual simulations should not carry the same weight as a validated simulation from a better-researched and better-known area. Also, the uses of unverified or quickly constructed simulations should become less precise. If a more trustworthy model with better information can generate useful numbers, a simulation employing unconfirmed information should be used for indications of trends, orders of magnitude, and general behavior. Working within a given information context requires some judgment about appropriate application of model results. Precision and accuracy may be less useful than the coarse behavioral patterns and relative timing of the behavior of important variables.

Accession, Storage, and Communication of Data. The ability of simulation models to help focus data requirements, and through sensitivity analysis, help prioritize those requirements, should greatly ease the task of those who inventory and manage data. Each simulation model generated with IPT should be in a position to help manage the data for other users. A Lotus data base is the current repository and data manager for the IPT models, although others may be useful.

Data extrapolation is important to development agencies which have many large projects that will proceed whether the data are good or poor, available or not available (or whether the specific data needed are even identified). It is likely that some types of data are likely to be more generally or widely usable than others. Identifying these more "portable" data types

is important because data collection efforts will not always be possible, particularly during the early stages of using a model as a project or policy planning instrument. Estimates of the statistical variation in existing and available data for data types would be useful. For example, less variance and more utility may be expected from extrapolated productivity figures for coral reef fisheries many kilometers apart but in a relatively constant environment, than for grassland productivity on the north and south slopes of a mountain only meters apart but with very different microclimates.

3.4.3 Model Development -- Encoding the Flow Diagram

Modeling and encoding a model are different but related activities. Elaborating a bit on the structure of Figure 3-7, we will illustrate the code for the birth rate inflow to the livestock variable from the existing code of the IPT Range, Livestock, and Wildlife model, and illustrate the fundamentals of encoding from a flow diagram drawn with standard System Dynamics icons. In Figure 3-8, each acronym is defined below each equation in which it appears, and again in an alphabetized documentation at the end of the model. Begin with the level (stock) variable Immature Livestock represented by the rectangle in Figure 3-7. Dynamo software uses arrays so that all four categories of domestic stock (large grazer, large browser, small grazer, and small browser) are represented by Livestock, although all equations are run for each class of stock separately with data collected for that type of animal. Since births increase

the number of Immature Livestock, that level variable is shown here.

For the sake of this example, let's ignore all but the inflow or Livestock Births, and break it down as an illustration of how to read and code the model in Dynamo. The variables which determine the birth rate are Mature Female Livestock and the Livestock Birth Fraction. Mature male livestock are not included because their absolute numbers are not important in determining the birth rate.

The livestock birth fraction is the percentage of a herd which is born each year. This is somewhat less than the genetic potential reflected in the constant, Maximum Birth Fraction, which embodies variations in age at first calving, twinning rate, and other non-environmentally controlled constraints to birth rate. The two major influences which modify the birth fraction are illness Effect of Morbidity on Births, and nutrition, Effect of Nutrition on Births.

These concepts of the model structure are encoded. Refer to the letters for the lines of code to each number in Figure 3-8. Line R,15, livestock births (LB.KL(RANGE)) (for both range areas -- cattle and game) between the current time (designated time K) and the next time we want to know (designated time L and over the interval KL), equals the number of mature female stock now, LIVSTK.K(MF, RANGE), multiplied by the current livestock birth fraction (on both ranges), LBF.K(RANGE).

On line A,16, livestock birth fraction (LBF) equals the maximum livestock birth fraction times the effects of nutrition and morbidity. The value for the maximum birth fraction is given as 0.9 in line P,16.1.

Line A,17 defines the effect of nutrition on livestock births (ENLB), which is expressed as a relationship dependent upon protein consumption. The effect of nutrition on livestock births (ENLB) is given by the DYNAMO table-look-up function TABHL. The nutritional effect is the dependent variable on the y-axis (values are 0,0,.1,.6, and 1 and are given in line T,17.1) as it responds to changes along the x-axis of the independent variable (which go from 0 to 1 in steps of .25). The independent variable is the fraction of the optimal consumption of crude protein for mature females: protein consumption per domestic animal divided by optimum protein consumption per domestic animal (PCPDA/OPCPDA). (See Figure 3-9.)

The effect of morbidity on livestock births (EMLB) isw defined in equation A,18. EMLB is shown to be an inverse function of livestock morbidity among mature females. As the fraction of mature female livestock (FLM.K(MF) increases, the multiplier decreases thereby lowering livestock births.

FIGURE 3-8 MODEL CODE FOR LIVESTOCK BIRTHS

```
lb.kl (range)    = (livstk.k(mf,range)*lbf.k(range))                          R,15
      lb         - Livestock Births (head/year) <15>
      range      - Range Areas <3>
      livstk     - Livestock (head) <11,12,13,14>
      mf         - Mature Females <1>
      lbf        - Livestock Birth Fraction (fraction/year) <16>

lbf.k(range)     = mlbf*enlb.k(range)*emlb.k(range)                           A,16
mlbf=.9                                                                       P,16.1
      lbf        - Livestock Birth Fraction (fraction/year) <16>
      range      - Range Areas <3>
      mlbf       - Maximum Livestock Birth Fraction (fraction/year) <16>
      enlb       - Effect of Nutrition on Livestock Births (dimensionless) <17>
      emlb       - Effect of Morbidity on Livestock Births (dimensionless) <18>

enlb.k(range)    = tabhl (tenlb,pcpda.k(mf,range)/opcpda(mf),0,1,.25)         A,17
tenlb=0/0/.1/.6/1                                                             T,17.1
      enlb       - Effect of Nutrition on Livestock Births
                   (dimensionless) <17>
      range      - Range Areas <3>
      tabhl      - DYNAMO table look-up.
      tenlb      - Table of effect of Nutrition on Livestock Births <17>
      pcpda      - Protein Consumption Per Domestic Animal (kg/hd/year) <59>
      mf         - Mature Females <1>
      opcpda     - Optimal Protein Consumption Per Mature Domestic Animal
                   (kg/animal/year) <127>

emlb.k(range)    = tabhl(temlb,flm.k(mf,range),0,1,.25)                       A,18
temlb=1/.75/.5/.25/0                                                          T,18.1
      emlb       - Effect of Morbidity on Livestock Births (dimensionless) <18>
      range      - Range Areas <3>
      tabhl      - DYNAMO table look-up.
      temlb      - Table of Effect of Morbidity on Livestock Births <18>
      flm        - Fraction of Livestock Morbid (fraction) <28>
      mf         - Mature Females <1>
```

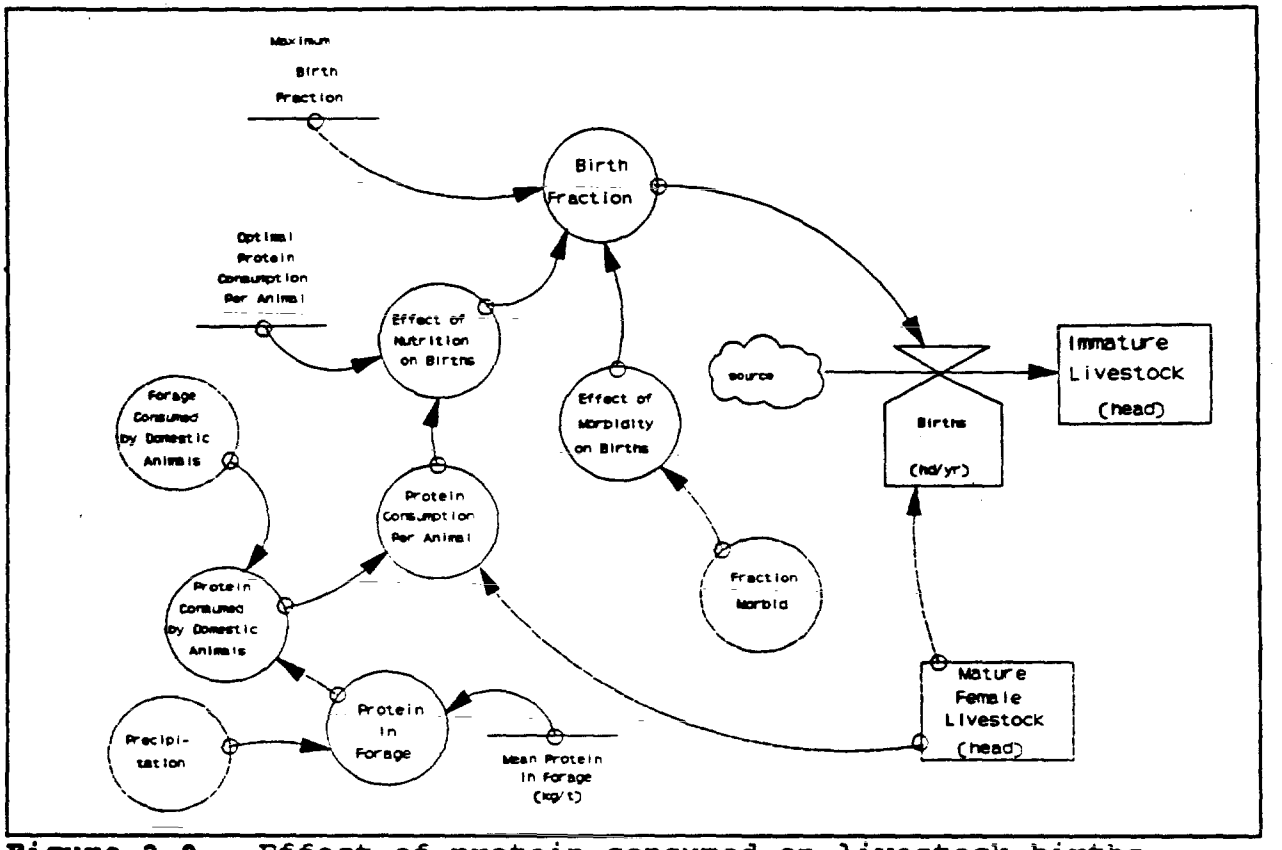


Figure 3-9. Effect of protein consumed on livestock births.

3.4.4 Model Development After Encoding -- Compiling, Debugging, and Testing

Dynamo will not compile without elimination of the errors in the code (debugging). These can be inconsistencies in the spelling, syntax, and grammar of the code, illogical construction, missing or unacceptable data, or other mechanical and conceptual errors. Although the Dynamo error checker produces error statements which are easy to follow and permit rapid identification and location of errors, modelers strive to avoid mistakes. As the modeler attempts to compile the model after typing in the code, Dynamo searches through the code several times, hunting for errors in equations. The Dynamo error checker ranks severity of errors from fatal to warnings.

The behavior of variables can show errors even when the model has been compiled and a Dynamo simulation proceeds without error statements. Bizarre behavior, such as negative numbers, can indicate conceptual problems such as an inappropriate time step (DT), or no minimum possible quantities (the MIN statement) put into the code to stop a variable from becoming negative. For example, if a model generates negative numbers of animals, it may be mathematically correct, but structurally incorrect.

One method of minimizing errors is to construct a model, particularly a complex model, in small discrete, logically consistent pieces, one variable at a time. When it is running well and exhibits the expected or reasonable behavior, other

pieces are similarly constructed. Eventually, the whole model is assembled and tested for consistent, explicable, and reasonable behavior. In addition, errors can be checked by cutting feedback loops and exploring the behavior of specific model elements.

The modeling process, beginning with the IPT workshop, is iterative. Even the products of the workshop can provide insights which influence a reformulation or restatement of the goals and problems -- a feedback type of educational process. Once the model has compiled, testing the model by trying different policies or data produces insights as the behavior is examined and data or formulas are altered. While the modelers progress toward a better understanding of the system, the model progresses toward utility for planning.

Explanations for simulation behavior can be found by working back through the structure and associated code. They can also emerge by analyzing the effects of structure -- particularly single feedback loops -- as agents of behavior. The loops can be isolated from the model one by one to assess their role and importance in the behavior (as can individual parameters and variables). Some loops are initially dominant over others, but this can change over time (the course of the run), as in the real world.

Such tests are accomplished, for example, by making a variable a constant, or by using one of Dynamo's test functions (steps, pulses, ramps, etc.). Another way of testing a model's

behavior is to set a single value extremely high or low so that the expected effect can be clearly assessed. In general, the loops and alternative structures for specific portions should be tested before the parameters are changed.

As noted previously, the tables represent auxiliary variables. They are a particularly powerful and useful feature of Dynamo and can be viewed as a related group of parameters. Dynamo curves are constructed and reviewed as they are projected from the computer to a screen at the IPT workshops. The table relationships are easily altered in the workshop by moving the projected line describing a relationship (for example, Figure 3-10) from the computer keyboard. Different slopes and shapes can be tested for the effect on important goal variables.

Testing a complex model is difficult for precisely the same reason it is needed. The many feedback loops, variables, and parameters can muddle the cause and effect relationships. Lest the complexity lead to anarchy, testing should be planned and proceed through a checklist of experiments, recorded observations, and explanations of the behavior. The analogy with inductive reasoning and the scientific method is clear. It is prudent to examine only one change at a time. Neither the model nor actual system interventions are likely to provide useful behavior if we randomly prod it because we don't understand it as a system.

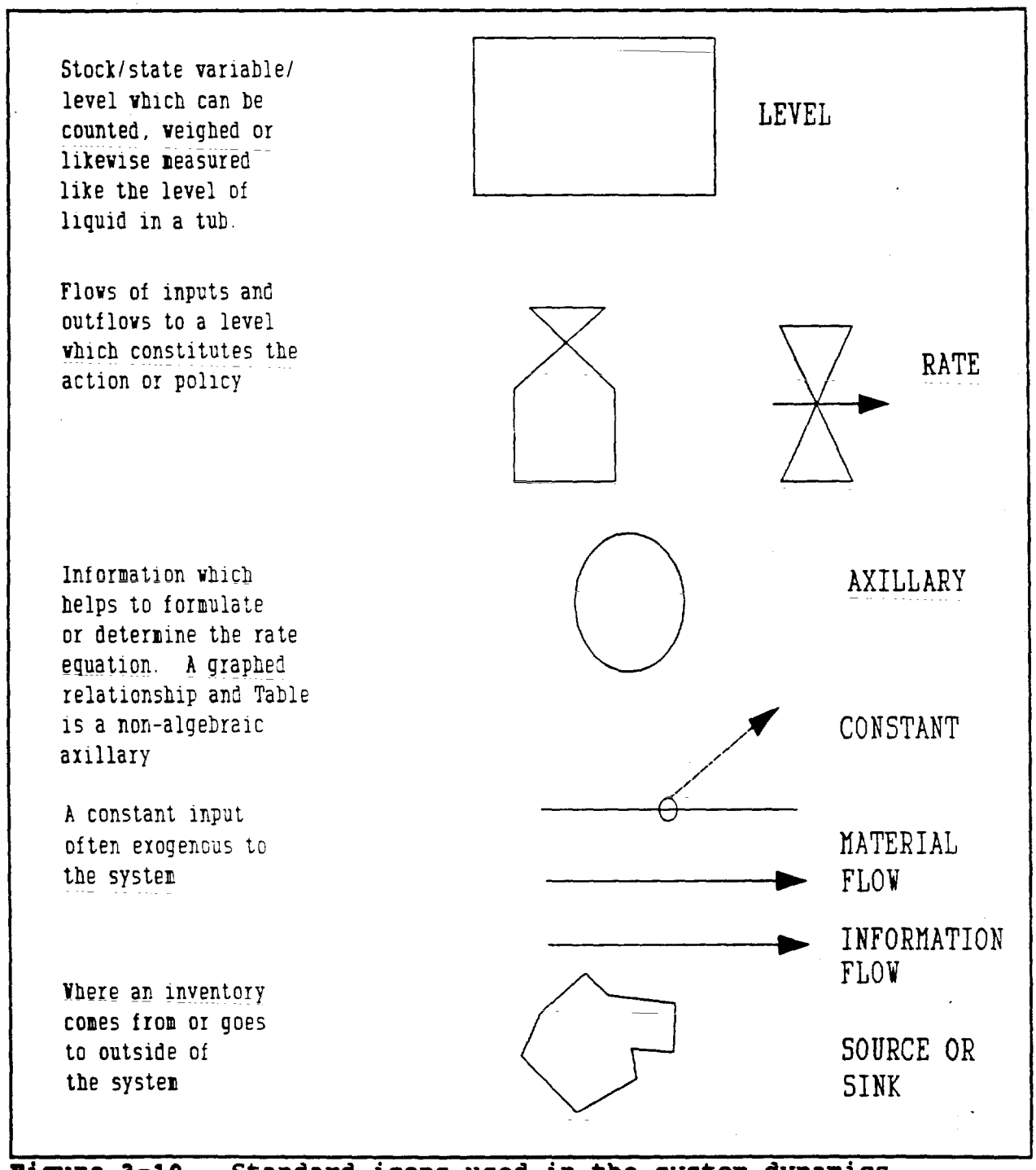


Figure 3-10. Standard icons used in the system dynamics.

3.4.5 Sensitivity Analysis

Richardson and Pugh (1981) identify three kinds of model sensitivity which can be tested: numerical (changed output values), behavioral (changed patterns, timing, shapes of curves), and policy (can enough confidence be placed in output which is stable enough to warrant its use).

These approaches to testing the model assist in judging its validity or credibility. Another product of such sensitivity testing is the determination of the relative importance of specific structural pieces (e.g., a certain process described by a causal loop) or individual parameters. This can be a very efficient and unbiased way of identifying critical system drivers for setting research priorities and acquiring information on these elements of the system. Both the corporate inputs of the workshop and the complexity of the system in its operation can largely rule out any chance that the outcome had been anticipated, or that bias or other corrupting forces dictated the research priorities. If the whole model behavior turns on a narrow range of values for several parameters, these are candidates for research or may be productive areas for policy intervention.

A judgment will need to be made about when it is best to freeze the model, assuming the behavior is satisfactory and the key questions can be addressed. It is an issue of human and

monetary resources as well as common sense, since the model will never mimic the real world perfectly. The perfect model will never be built.

3.4.6 Model Development -- Requirements

Professional Dynamo, which is used on MS-DOS microcomputers, costs about $2,000 (1989) and requires several months of reading, use, and tutoring to acquire some encoding facility. Obviously, the ability to depict structure in code appreciates with knowledge of the system under consideration and experience with Dynamo. A run-only version, which permits policy testing by changing initial values, does not require encoding ability but does assume system understanding. Our run-only Range, Livestock, and Wildlife model requires only that the user type "range" and follow instructions in a series of menus. It is important to understand the structure and theory of the model to best appreciate and interpret its output. This run-only model can be requested from the authors. It is the same system depicted in the following chapters.

STELLA, a computer language for Apple Macintosh microcomputers, costs about $350 (1990), and also requires a significant investment of time. Most inputs employ a mouse to construct graphic representations of a system and to select the coding and analysis alternatives. Dynamo uses a keyboard, textual instructions, and menus. STELLA models are constructed by building flow diagrams with the computer and mouse, and then

defining the equations from prompts derived from the structure. The software cleverly assesses the structure and informs the modeler of the terms required for each equation. The use of full words rather than the acronyms of Dynamo also render the model explicable to those who did not personally build it. The model is build in STELLA by associating icons, thereby eliminating the need to use additional software in the additional chore of rendering Dynamo code into graphic flow diagrams.

Chapter 4

RANGE, LIVESTOCK, AND WILDLIFE -- AN INITIAL FOCUS FOR IPT

		Page
4.1	Focusing on Range, Livestock, and Wildlife	152
4.2	Range Ecology and Management	154
	4.2.1 Definition	154
	4.2.2 Ecology	156
	4.2.3 Management	167
4.3	Population -- the Most Significant Ecological Factor	169
4.4	Review of Range Development Approaches	171
4.5	Problems Resulting From Development Attempts	173
4.6	Toward Sustainable Rangeland Uses - Game Ranching & IPT	179
	4.6.1 Social and Economic Considerations Favoring Wildlife	180
	4.6.2 Ecological Considerations Favoring Wildlife	185
4.7	Status of Game Ranching	196
	4.7.1 Meat Production -- Cattle and Wildlife	196
	4.7.2 Safari Hunts	200
4.8	Summarizing -- a Rational Transition	202

4.1 Focusing on Range, Livestock, and Wildlife

During the evolution of the Integrated Planning Technology, we analyzed several of the renewable natural resource sciences with IPT for potential research and project applications. Forestry, coastal resources, and significant elements of the social, economic, and agricultural sciences had been developed from workshops, through data collection, to simulation models. These areas of the applied sciences reflected current interests of the Office of Forestry, Environment, and Natural Resources (FENR) of USAID's Bureau for Science and Technology. Following an interim assessment, the review committee suggested that we focus and validate a model. We chose the range, livestock, and wildlife sector for intensive development and field validation because a compelling array of tropical rangeland attributes currently warrant treatment by a method such as IPT:

- apparently intractable management problems have made international assistance generally ineffective, and development agencies are retreating from involvement in this biome;
- rangelands are deteriorating at an alarming rate due to desertification, which degrades spectacular natural systems and reduces millions of people to starvation;
- these areas (including range outside of the tropics) are extensive, and cover half of the earth's land surface;
- excellent, long-term data sets exist;
- pastoral systems are not only threatened, but display the complexity and diversity which are the precise characteristics an Integrated Planing Technology should be able to best address;

- rangeland systems are clearly linked to the sustainability Of productive adjacent or downstream systems such as agriculture and fisheries;

- the likelihood of new management initiatives and approaches being accepted, used, and dispersed is greater because of the problems experienced by the institutions attempting rangeland interventions;

- a nascent move toward conserving the enormous productive potential of natural rangeland products (for example, game ranching) has both stagnated and paved the way for further development and wider acceptance of new approaches;

- the authors bring some personal experience, training, and expertise in these particular areas of applied ecology.

4.2. Range Ecology and Management

It is important to understand enough about rangelands to appreciate the goals, issues, and the structure of the Range, Livestock, and Wildlife model described in this book.

4.2.1 Definition

The earth's rangelands are generally arid, rough areas with natural, largely unmanaged vegetation unsuitable for conversion to other uses. Nearly 60 percent of all range is considered arid to semi-arid. Rangelands occupy nearly half of the earth's land surface (Heady, 1975), which is comparable to the percentage area grazed by livestock in the United States (Stoddart and Smith, 1955). By far the largest rangeland area occupies the second largest continent. Over two thirds of Africa constitutes 30 percent of the earth's rangeland. The world's rangelands are inhabited by about 250 million pastoralists (Western and Finch, 1986), who are threatened by a complex of modern changes. To the range manager, rangelands are primarily used to produce vegetation (primary production) for grazing (grass eating) and browsing (woody plant consuming) livestock and wildlife, which convert their food to meat in a process called secondary production. Other important considerations such as maintaining watersheds, biological diversity, and recreation, are of increasing importance and require careful definition of the term "carrying capacity" (i.e. for what?).

Rangelands, as much as any land category, are defined by an overwhelming issue -- they are rapidly disappearing as productive systems through the process of drying to deserts, most of the time because of inappropriate use. Estimates of desertification rates vary. Dregne (cited in Grainger, 1982) contends that desertification claims 200,000 square kilometers each year, an area the size of Senegal. Estimates of desertification in the Sudano-Sahalian and southern African regions range between 80 and 90 percent of all rangeland (Mabbut, 1984). Although desertification is an unsatisfactory description (it impugns deserts, which are a perfectly healthy, functioning, and interesting natural system), it is commonly used to describe a human-assisted process of the soil and vegetation drying (actually xerification), which greatly reduces productivity. Although the definitions are disputed (some require that reversal or rehabilitation is not naturally possible and requires substantial interventions), and data regarding the phenomenon are spotty and questionable (Nelson, 1988), there is no doubt that it is a serious global problem. Desertification has degraded over 80 percent of all rangelands and contributes to ecological stresses and famine, for example, the deaths of nearly 500,000 Ethiopians during the 1984-85 drought and mortal risk to 5 million people in the Sudan and surrounding areas in 1988-89 (ERS, 1989).

4.2.2 Ecology

Several well-known ecological processes must be understood and managed for most rangeland development activities to achieve their goals. How these systems may work and why the Range, Livestock, and Wildlife model is structured as it is (Chapter 5) are discussed in the next five subsections.

Each principle described is linked to some rangeland processes, and with management activities which should consider the principle and process.

Disturbance and Succession. Rangeland vegetation reflects the influences of weather, climate, topography, edaphic (soil) factors, fire, and use. Typically, management units of 1,000 to 10,000 hectares reflect these influences, and the vegetation is in different stages of succession from the effects of disturbance. It matures through a series (more accurately a continuum of several successional (seral) stages) toward a theoretical equilibrium (climax), each with a characteristic mix of species and productivity. This landscape mosaic of derived and more mature vegetation communities supports closely associated faunal communities. Typically, productivity is higher near the climax stage with a high proportion of palatable, productive, nutritious, and available perennial plants. The extent to which this holds in tropical African rangelands needs evaluation because of millennia of anthropogenic manipulations. These late successional plants are more nutritious to ungulates

and tend to decrease under excessive grazing. Hence, they are known as decreasers and are supplanted by increasers, which are generally less useful as forage (Dyksterhuis, 1949). Continued overuse leads to greatly reduced productivity and introduction of invaders, which are often exotic, unpalatable, or poisonous annual weeds. The condition, carrying capacity, and trend of rangelands is in part defined by the species mix from these successional stages found on a particular site. In the United States, the species are scored to determine prescriptive details of such management practices as desired species mix, stocking rates, dates of allowable use by livestock, and rehabilitation treatments. This evaluation of the successional stage or health of the range system is used by land management agencies in the United States in a process to determine proper use and stocking rates called range allotment analysis (USFS, 1980).

Cycles of vegetation disturbance and succession on a habitat (for example, small watersheds) may reach an equilibrium over ten to twenty years.

On a smaller scale of one to one hundred hectares, the natural seasonal use patterns of low relief features such as ridges, slopes, and swales (known as a catena) typical of large rangeland areas also result in different stages of forage availability and succession. When coarse feeders such as zebra eat large stemmy forage, smaller, more delicate and digestible plants (or their parts) are available to a sequence of smaller

herbivores. At the end of the year, only short grasses and forbs (wide-leaf herbaceous plants or "weeds and wildflowers") are available to more selective small herbivores such as gazelle (Bell, 1971). This process facilitates use of a single area by many species, and the resulting small-scale successional processes recur each year.

On the other hand, range ecologists are just beginning to see evidence for much longer cycles of vegetation and habitat. Sinclair (1978) and Ellis and Swift (1988) note evidence for longer cycles on the order of a century or more. Herds of browsing animals such as rhino and elephant use and modify woodland habitats so that slash, debris, and grassy trails render such vegetation types vulnerable to fire. Eventually, the woodlands recede under heavy use and fire, and give way to expansive grasslands. Elephants disperse and die (as at Tsavo Park in Kenya) to be replaced by grazing herds of wildebeest, gazelle, zebra, hartebeest, ostrich, and other animals, which increase in response to increased grassland forage. They then begin to modify the grassland. Their increasing use generates a competitive advantage for shrubs and trees. Many animals in this grazing community disperse, die, and the cycle is repeated on a large scale (Sinclair, 1978).

For example, wildebeest increased in the thousands of square kilometers of the Serengeti ecosystem of Tanzania and Kenya, from about 250,000 in 1961 to nearly 1.5 million in 1977 (Sinclair and

Norton-Griffiths, 1982). Such long-term dynamics may not be perpetuated by density-dependent biological agents such as grazers and browsers. Ellis and Swift (1988) invoke possible climatic shifts or very strong feedbacks (described below) as initiators of change. Although they consider density-independent catalysts such as drought to be random, in fact their occurrence is an eventual certainty and even seems to exhibit some cyclic pattern (See Figure 6-3). It appears that several successional events are occurring on some rangelands simultaneously on different scales of time and space. These scales can impose important constraints on rangeland management efforts. Many interventions have failed because one or more of these cycles and their agents have not been recognized -- hence, it appears as though development has employed an erroneous paradigm (Ellis and Swift, 1978).

Forage Defoliation. Generally, many plants react to partial removal of live herbage (defoliation) by elaborating plant and growth hormones which stimulate growth, branching, or seeds (Heady, 1975). McNaughton (1978) describes enhanced growth of up to 50 percent due to the application of saliva by animals while they graze. Banyikwa (1976) measured a 60 percent forage increase when ungulate dung enhanced fertility. In other words, proper use enhances the productivity of favored forage, and managers attempt to define appropriate use levels and stock to them. If, however, grazing and browsing lead to defoliation levels beyond the capacity of the plant to restore itself, the

plant's effort to produce more leaf area for photosynthesis increases physiological stress and decreases root and seed production. The plant robs its roots, which drastically decrease in density, and are therefore unable to capture as much soil moisture -- a critical factor in typically dry rangelands. Various experiments have shown root reductions of 80 percent or more after clipping to simulate grazing (Robertson, 1933; Harrison, 1931; Oswalt et al., 1959). The amount of herbage removed (intensity of defoliation) interacts with the characteristics of each species. Observations indicate that about half (in some species more, some less depending on the timing, frequency, and species) of annual production can be removed before consumption-induced stress leads to such loss of vigor that less palatable competing plants increase and take over. In a stocking rate experiment based on one square mile (257 hectares), Johnson (1953) compared the effect of grazing by 53, 47, and 27 cattle. Halving the cattle actually resulted in a one-third increase in dollar return for beef and directly reflected changes in the vegetation and weight gain of the cattle feeding on it.

Most plants are extremely sensitive to the season of defoliation; they are most vulnerable in early growth stages at the onset of rains, or in the spring. For example, experimental clipping of wheat grass in the spring reduced yield by 85 percent and repeated clipping eliminated the species in three years (Blaisdell and Pechanec, 1949). Fortunately, the entire

community of forage species at a site exhibits staggered growth and maturation. Animals can impose proper use (a term implying maintenance of the diversity, structure, and productivity of the system) on this phenological schedule. To minimize damage, they can rotate their use if early season initial use is deferred or dispersed. Migrating wild herds can arrive at a particular time to accomplish this, or rotate the areas of use from year to year. Observations of the intensity, frequency, and seasonality of forage defoliation by wildlife have led to several livestock grazing systems. For example, short-duration and deferred-rotation grazing systems exploit these characteristics of vegetation response to use (Savory, 1988). Short-duration (or multicamp) grazing schemes from southern Africa promote brief, intense periods of overgrazing and trampling punctuated with rest periods. They depend on fairly elaborate and expensive fencing and pasture design (Goodloe, 1969; Roux and Skinner, 1970; Savory, 1988). Such a regime prepares the soil, plants the seed, and eliminates selection of decreaser species through near-complete and equitable use of all vegetation, reducing the grazing-induced competitive advantage of increasers and invaders. This grazing system is controversial, and measurements of its effects have not been conclusive. A deferred-rotation grazing system has been used in Texas and East Africa with "impressive results" (Heady, 1975). It employs three herds and four 22"pastures", each grazed year-long for one year in a four-year cycle, ungrazed for four months twice in the cycle, and deferred

when most vulnerable (in the spring) once in the cycle (Merrill, 1954).

Co-evolution. Adaptation of vegetation and herbivores to using each other has led to co-evolution. Co-evolved plant strategies include:

- the deployment of spines (e.g., Acacias),
- needle-like awns (e.g., Sitanion squirrel grass),
- toxic chemicals (e.g., Cymbopogon turpentine grass seed heads, sage leaves),
- near-ground protective buds and stems (stolons), and
- below-ground stems (rhizomes) of sod-forming grasses where herds of bison, wildebeest, or other hoofed wildlife would have damaged plants above the ground (e.g., Buchloe buffalo grass of North American prairies, or Cynodon stargrass of East Africa).

Productivity, Soil Integrity, and Desertification. Successional increaser species in overgrazed areas are often annual grasses or forbs which flower, set seed, and die in a single year. Annual plants are often worthless as forage during the dry season when they have matured and died. But since annuals disperse thousands of seeds which can remain viable five to ten years (some to two hundred years), they are valuable to establish cover and provide forage after overgrazing, drought, or other catastrophes. Perennials often provide good forage throughout the year, and during the dry season the remaining stubble and roots provide stores of energy for rapid growth when moisture becomes available again. These perennials provide highly productive forage, for example, 2,000 kilograms per hectare in 700 mm rainfall belts

compared to 300 kilograms per hectare for annuals on a similar site (Berwick, 1976). Perennials are also relatively nutritious (10 percent crude protein compared to 2 percent for annuals).

Perennials also enhance the productivity and conservation of a site. The elaborate root systems bind the soil against the pressure of trampling and erosion, and capture scarce, infrequent precipitation. A single grass plant examined had 13 million root members, a root length of 387 miles, and a surface of 4,321 square feet -- 130 times the above-ground parts (Dittmer, 1937). Although annual roots only penetrate the soil about 30 centimeters, perennial roots can penetrate to over 6 meters, and weigh between 2 and 4 metric tonnes per hectare. Since roots are rapidly replaced, they contribute significantly to the soil organic content, and enhance its fertility (Shivley and Weaver, 1939). These roots have an enormous effect on water infiltration in dry areas, providing channels of rapid entry before evaporation or erosive run-off render rainfall useless (or harmful). A comparison of under-grazed and over-grazed sites showed a five-fold decrease in water infiltration (Flory, 1936) and a sixty-fold increase in soil run-off loss on the heavily grazed site (Craddock and Pearse, 1938). A single year of protection decreased the soil compaction of trampled, overgrazed areas by one half and increased water infiltration six-fold (Berwick, 1976).

Cycles, Population Dynamics, and Density-Dependent Feedback. The challenge of range management goes beyond the manager's perception of structure and process, and lies partly in understanding the interaction of different rates or time scales of events such as population growth. In an exceedingly simple example, the generation time of gazelle may be three years, of a vegetation community, thirty years; and of the soil (to form one centimeter), three hundred years. However, management of these resources often reflects a project, bank, or political half-life. Different rates of growth or weathering, the various cycles and their interacting effects, i.e., the facets of system dynamism, do not command our attention in the way that structure does. We are often surprised by the action of rates and cycles in systems we attempt to manage.

For example, a foot and mouth disease control effort to eradicate deer in a large forest in California was deemed successful until two years later when as many deer were being shot during the hunting season as before the "eradication." Twenty-three years of an expensive eradication effort in Botswana failed to eliminate large mammals from a tse-tse control area (Child et al., 1970). These examples illustrate the enormous productive capacity of populations below carrying capacity. Thompsons gazelle can increase at 40 percent of the herd per year under such conditions. Furthermore, it has been well documented that such approaches to exponential growth, unless harvested by

predators or man, will soon exceed the carrying capacity (Rasmussen, 1941; Sheffer, 1951).

This tendency to exceed carrying capacity in the absence of regulation happens normally each year in the annual cycle of wild animal populations. In a natural situation, the excess animals are removed by disease, starvation, predators, accidents, and other mortality factors (Leopold, 1933). These factors interact. For example, if predators are removed, other factors compensate so that at the beginning of the annual cycle (just before the birth season), the number of animals in the population is the same as it was in the spring of the previous year. This theory of intercompensation was empirically observed and experimentally measured in wild animals (Palmer, 1956), and is one basis for harvesting the doomed excess, or "shootable surplus", which would be lost to another factor such as disease. It implies sustained yields of stable populations (Errington, 1938), however, the real world is not always as predictable, and some of the management challenges are difficult. For example, a hunter is not likely to select the same animals which disease, predators and other natural factors would cull. Therefore, in some cases population genetics must be considered, which will depend on the size, isolation, breeding habits, and other characteristics of the population. As we have already mentioned, nature is dynamic and system changes rarely allow stable populations in constant environments. Sensitive and constant monitoring and management

are required as in the case of the Zimbabwean ranch and the trends of its carrying capacity described in Chapters 5 and 6.

The consequences of population growth in the absence of regulation are dramatic because of the explosive nature of exponential growth. With unregulated growth, carrying capacity is exceeded over a much longer time period than during the annual cycle, with more long-term consequences for the ecosystem than the boom and inevitable crash of the population. May (1973) has modeled such systems to clarify the conditions of equilibrium. Empirical observations, however, indicated that explosive populations and overgrazing which occur when ungulates are not controlled can lead to sudden dramatic die-offs to near extinction of both forage and herbivore (Sheffer, 1951). Dasmann (1981) notes that large herbivores "hang on ... and can continue to depress forage plant production." However, because of the difference in generation time in the plant community, it may take many more years to recover than herbivores.

During the period of overuse, erosion occurs, fundamental site conditions change, and the initial system changes. These different rates of change and the eventual effects of different interacting time lags are difficult to project. Feedback is likely to be stronger when certain lags coincide and interact, even though their period and magnitude may differ. One example of the management implications, described in Chapter 6, Sections 6.3 and 6.4, is when the effects of the ranchers' inability to

react to reduced soil moisture appear to be additive and depress animal productivity well after a poor rainfall year occurs.

We have described a system characterized by a variety of stresses to which it is resistant and to which it exhibits restorative power -- but only up to a point, after which the system changes. A focus upon the defoliation of characteristic vegetation illustrates some of the processes which underlie management. The processes briefly described above include selective herbivory, water capture, nutrient cycling, productivity, succession, facilitation, niche segregation, competition, co-evolution, and life-history strategies of animal populations. All of these ecological processes respond to several scales of space and time. These factors and many others are inextricably linked and represent an elaborate structure which describes rangeland ecosystems and opportunities for managing them. They underlie the attempts to integrate wildlife husbandry with livestock for subsistence and commercial gain. The employment of these principles is still tentative and efforts to do so will be described below.

4.2.3 Management

Range management employs ecological principals such as those described above, to improve or protect the basic range resource variables such as soil, vegetation, and animals, while attempting to achieve optimum production of goods and services in whatever combination policy may determine is desirable (Heady, 1975).

Often, the emphasis of the range professional is on forage production by the natural system, although agronomic practices such as seeding, irrigation, and poisonous plant control are practiced. Considerable skill is required not only to understand underlying ecological principles, but also in selecting goals and choosing alternative management techniques which consider these principles.

The primary strategies employed by the range manager are:

- improving the range by removing invading shrubs to favor grazers such as cattle, seeding, water capture, and prescribed burning; and
- altering grazing and browsing conditions by changing the mix of animal species, manipulating animal densities, managing animal distribution upon the vegetational mosaic, and controlling the seasons of range use.

All of these efforts to manage grazing factors (Heady, 1975) are designed to direct the vegetation and soil toward some specific products which are sustainable. Sustainability implies maintaining all range use options for future policies and uses. The grazing factors include aspects of defoliation (the intensity, frequency, selectivity, and season of vegetation use) and the distribution of plants, minerals, and other herbivores.

4.3 Population -- the Most Significant Ecological Element

An examination of several current issues which relate to African rangeland systems should tie the description of ecological processes to specific existing problems, and prepare us to examine the responses of international development assistance in this sector.

For the millions of people living in unbuffered proximity to African rangelands, the ecological principles just described are important to their own population dynamics as well as to wildlife populations. Human population growth, although clouded in detail, will increasingly exceed the carrying capacity of large areas of sub-Saharan Africa. The human population will nearly triple between 1970 and 2000, and is likely to stabilize at 1.8 billion if massive mortalities do not intervene. Kenya's population will double every eighteen years at current rates. The demand-supply shortfall of population and natural resources is spotty in distribution, although for some areas the challenge is stark and clear.

Over sub-Saharan Africa as a whole, population will grow at over 2 percent per year and cereal production at 1 percent, but livestock production per person will decline at 10 to 15 percent a year (Simpson, 1984). To merely maintain existing per capita meat consumption (at one tenth that of Australia), sheep and goats would have to more than double to 700 million animals, unless substitutes for domestic stock can be developed. Recall

the capacity of populations to overshoot their carrying capacity, degrade long-generation resources, and change the existing equilibrium of the ecosystem.

An example of the absolute requirements of a subsistence pastoral family in northern Kenya is given by Pratt and Gwynne (1977), using figures which are typical for much of the Sahel and eastern Africa. Milk supplies 75 percent of the food calories of these subsistence, nomadic pastoralists (15,000 per day per family). Such a food source requires keeping at least 44 cattle and 100 goats or sheep for meat. Range carrying capacity is often 1 cow per 15 hectares, or 3 people per square kilometer, which is less than what is currently living in the area.

Cultural as well as economic factors often determine herd size. For example, pastoralists in southern Zimbabwe keep an average of eleven cattle, five donkeys, six goats, and other small stock. Some of these assets are dictated by the need for draft power, milk, meat, and manure. A bride price, however, dictates the gift of a male animal to the father-in-law and a heifer to the mother-in-law (Chavunduka, 1985). Stocking rates are about twice the calculated carrying capacity of the low veld (ARDA, 1983), range degradation is widespread, 80 percent stock losses occur during drought periods, yet human populations and their cattle are growing at 3.6 percent per year.

4.4 Review of Range Development Approaches

Over the past quarter century, international assistance for range development has been characterized by a number of approaches which have clearly not worked as well as anticipated. Two types of activities dominated:

Ranching. Attempts were made to reduce overuse of the common range resource by conferring ownership and by encouraging commercial rather than subsistence pastoralism -- ranching. These policies reflect governments' desire to have more control over the sector and sometimes over the pastoralists themselves, as considerable cultural changes are a corollary in the shift to commercial ranching. They also reflect the prior experience of foreign advisors in ranching and animal sciences (as opposed to other approaches such as watershed or range management). The policies were based on a positive correlation between ownership and better stewardship as an expression of self-interest, but the aftermath of such policies has included cultural dislocation with reduced quality of life and cultural extinction. The Kalahari bushmen, the Tswana chiefs in Botswana who have lost influence (Bekure and Dyson-Hudson, 1982), the Mbeere of west Kenya where suicides and out-migration have become new demographic factors (Schneider, 1984), are a few examples. Lest we lose perspective, this is similar to the history of rangeland development around the world. In the United States, for example, government policy for native Americans had predictably disastrous cultural and

ecological results. Rangelands in the United States lost much of their integrity and productivity in the first fifty years after livestock were introduced and the deterioration of tribal rangelands exceeds the average. In 1936, 84 percent of American rangelands were in unsatisfactory condition. Today between 60 and 81 percent remain in unsatisfactory condition (Barton, 1987).

Technical Packages. Imported approaches for range and livestock in the developing tropics emphasized ranch management and animal sciences. These technical packages require the skills of experts such as veterinarians, hydrologists, nutritionists, economists, and agricultural engineers. Inevitably, the emphasis on the product (meat), rather than the resource base upon which the products depend (the range), has generated a very focused, discipline-related, eccentric approach. Borehole development, tse-tse control, farm-to-market infrastructure, and other projects have almost always suffered fatal, unanticipated surprises (USAID report of the expert committee on African range and livestock,, 1985).

4.5 Problems Resulting From Development Attempts

The interaction of intense demands upon rangeland resources due to human population pressure, along with top-down modernization and archaic modular planning, has generated problems. A partial list should demonstrate the consequences of such approaches, and help to indicate what any proposed solutions would have to address.

New Skills. As tenure and hierarchy change with an emphasis on ownership and sales, new skills and broader external relations are required. The meeting of cultures and the interactions which negotiations demand can have different impacts, and to some, the effects could be devastating.

Environment and Development. An increasingly polarized debate is occurring between advocates of complete protection (for example, the 1977 law banning hunting and increasing park and protected areas in Kenya), and advocates of increased livestock production. At their extremes, neither approach incorporates a mix of potential goods and services representing whole-system outputs reflected in the definition of range management cited earlier. This polarization is dictated by respective single-interest and single-discipline approaches to a complex natural system. The choice has been environment or development, when for most areas only both are possible. This is a familiar debate in many parts of the world. The U.S. agency responsible for the largest area

of rangeland, the BLM (Bureau of Land Management), has been pejoratively called The Bureau of Livestock and Mining.

Planning for the Unexpected. The reductionist focus on one or two product-centered elements of the whole range system has yielded consistent failures because of the unexpected intrusion of elements such as drought, social unrest, resource migration, and wildlife damage -- all of which could be planned for, if not predicted. For example, of the six African range and livestock sector project audits evaluated by USAID's expert panel, the most successful had dropped all range management components and achieved less than 5 percent of its cattle marketing goals (the AID audit for Senegal).

Not Enough Time. The project time frame is far too short to effect meaningful ecologically-related interventions, measure the results, employ personnel who return from training, or plan the project while cognizant of the several kinds of natural cycles noted earlier. Nevertheless, it reflects the dominant paradigm of range development as described by Ellis and Swift (1988). This inappropriate treatment of the time frame for planning results in surprises. The unexpected events may appear random (e.g., Ellis and Swift's "stochastic" events or Hollings' first and second types of risk, but can, in fact, be accounted for in planning a program or project. Our analysis of several range management policies indicates a significant payback on

investment, but it requires nearly 20 years. The system responds on its own schedule.

Lack of Expertise. The failure of interventions can generate a retrenchment among the responsible agencies. In the case of USAID, this seems to have resulted in a circular, chicken-and-egg problem. A near absence of AID staff with the skills needed to address rangeland development issues reflects a disengagement from this difficult sector. Without direct-hire staff to identify issues and responses, write terms of reference, exercise quality control and monitoring functions for projects, organize internal advocates during budget debates and allocation, and advance the field through development-related research, the Agency insures further difficulty because of its reduced capabilities. It also results in a curious kind of amnesia about past attempts to develop rangelands and prevent desertification -- a lack of analysis and memory. Reviewing the effects of earlier meetings on the topic, one AID staffer noted that "very few projects that reflected the (earlier) thinking . . . could be cited (Atherton, 1979).

The quiet but clear decision by some of the major donors to back away from the enormous areas of rangeland, its resources, and people, and to focus on areas which they have been more successful is difficult to document. USAID is not going to vigorously engage itself in this sector. It will focus on the 10 percent of sub-Saharan Africa considered arable and to which it

can apply its demonstrated skills in agriculture and forestry. The World Resources Report (1988-9) notes that "... most (rangeland development efforts) have failed to achieve their objectives and have been abandoned." Thomas (1987) wrote that "...the Administrator of USAID called...us...to respond to the following statement: 'in light of the failures of the past fifteen years of interventions designed to manage the rangelands in sub-Saharan Africa, should AID try to promote the development of sustainable extensive livestock production systems in that region?...one alternative raised has been for USAID to desist funding extensive livestock development programs altogether.' Needless to say our panel responded with strong recommendations for USAID to continue... Our recommendations went virtually unheeded. Over the past five years USAID has systematically phased out nearly all range programs."

Nevertheless, parts of AID (for example, the Bureau for Science and Technology) are concerned about the situation and are making attempts to identify some useful next steps (e.g., an animal agriculture meeting in 1988 and a white-paper consultancy in 1989). In other donors (or offices within them), rangelands are a forgotten half of the earth. The World Resources Report notes that globally, multilateral and bilateral development commitments to livestock-related projects, as a share of all agriculture, forestry and fisheries, fell from 3.5 percent during 1977-79 to 2 percent in 1983-84 -- most in rangeland projects. A March 1988 memo in the World Bank indicated that rangelands did

not warrant attention in focusing initiatives of the Bank's wildland policy (Mittermier, 1988).

Top-Down Planning. A top-down approach to planning range intervention rarely involves people at the point of application, and thereby loses the insights and acquiescence of the stockowners who ultimately manage the range. The reasons for this planning mode are obscure. Top-down planning characterizes efforts generated at a capitol city, or by planners who may not be familiar with the topic, by cultural impediments (including language) to dealing with stockowners, by the expense or inconvenience of meeting, or by special interest lobbies. IPT is an effort to break through this impediment to informed planning and informed acceptance.

Polarization. An increasingly polarized debate between advocates of complete wildlife/wildland protection (e.g. the 1977 hunting ban in Kenya) and advocates of increased livestock production anywhere is deflecting attention from the remaining efforts to sustain the mix of potential goods and services representing whole system outputs. Single interest/single discipline uses foster the polarization -- e.g. environment or development.

In summary, the overemphasis on bits and pieces of a system, nearly exclusive product orientation, inappropriate time frame, lack of expertise, parochial bias of the obtainable expertise, training for commercial goals in temperate economic and range systems, historical ignorance, and top-down approaches together

illustrate an inability to either develop strategy or plan projects for sustainable rangeland use. The failures become explicable.

4.6 Toward Sustainable Rangeland Uses -- Game Ranching and IPT

Our work with African rangeland issues since 1973 has pointed to useful and acceptable range conservation initiatives. Views represented in this analysis include perspectives from subsistence and commercial pastoralists, and government and donor development planners. They incorporate insights from the ground up.

Broadly, three challenges need to be addressed:

- population growth rates and resultant demands upon the range resource,
- improved planning for rangeland use, and
- restoration of over half the range area which suffers greatly reduced productivity due to degradation.

Although adaptive planning, restoration, and improvement techniques exist, they have not been adopted by potential users. They also tend to be conceived as required at opposite ends of the development process -- planning at the beginning of a project and mitigation of impacts and restoration at the end. Unfortunately, shortcomings in planning make range restoration necessary as a part of the planning process. Virtually every rangeland region has simultaneous planning and restoration requirements.

In an honest analysis of past failures lie the seeds of success in developing rangeland systems while at the same time conserving them. More informed and better planned proactive

involvement in development assistance is essential, or inevitably it will be necessary to combat the symptoms of decay -- poverty, food aid, political instability, loss of existing development investments, and loss of biological diversity.

We must develop management levers immediately. The ecological, human, and economic costs of business as usual are not tolerable, and soon there will be no home on the range for most of its inhabitants, human or animals. Two of the most promising management technologies are described in this book: Integrated Planning Technology and the commercial uses of wildlife such as game ranching. These two management innovations employ a modest amount of modern technology, and are also related: game ranching can use IPT. Game ranching can be a profitable test bed for using IPT toward sustained rangeland uses.

4.6.1 Social and Economic Considerations Favoring Wildlife

Humans emerged as hunter-gatherers in Africa, evidently in the ecotones (intermediate edge habitats) of the woodland-savanna. These areas still support a Pleistocene fauna distinguished by its great diversity and abundance (Weiner, 1971). Unless population growth and development rapidly change life styles, many Africans will continue to hunt and gather as a significant activity. About 75 percent of sub-Saharan West Africa still depends largely on traditional protein sources -- not only large wild grazers and browers, but also birds, fish,

maggots, snails, and insects. This surprising evidence of the essential role of "bush meat" is summarized from data for Sudan, Ivory Coast, Nigeria, Ghana, and Liberia (Assibey, 1977). Wildlife constitutes about 40 percent of the diet in most of Botswana (Richter, 1969). About 2.5 million springhare are killed each year in Botswana for food valued at $1.5 million. For those tribes that have maintained a hunter-gatherer life, game is not only essential but provides a sustainable yield most appropriate for their habitat. The following figures should be periodically updated in the face of subsidies, deculturation, migration, and modernization. The Hazda of central Tanzania have a nutritionally adequate diet and spend less time obtaining it than nearby agricultural tribes (Field, 1979). Kalahari bushmen average more protein than Americans, virtually all from wild animals. During the season when ungulates are scarce, other protein sources such as termites are exploited, which takes about half the week. Their caloric intake also exceeds caloric requirements (Field, 1979; Silbauer, 1981). These relationships between such tribes and wildlife can be found throughout Africa, for example, the Bisa of Zambia (Marks, 1977), although tradition and tenure are changing.

The modern proliferation of game preserves, hunting concessions, and ranches have limited traditional access to game, seen by the Waliangulu of Kenya. The local consequences can be quite devastating. Asibey (1974) notes that some countries are now importing protein to overcome deficiencies, which is not only

a foreign exchange burden, but rarely does the meat reach those who need it and who can least afford it.

Most countries actively promote livestock as a replacement for game protein, but this policy can have several unfortunate consequences. Policies which encourage group ranches and tenure changes generate changes in tribal hierarchies and expectations. These changes alter traditional management and communications practices. The ecological effects of uncontrolled (or uncontrollable) grazing have also been reviewed, however additional health and economic problems have surfaced as well.

Cattle are generally heavily subsidized by the government at the people's expense. For example, to generate US$31 million in foreign exchange through beef sales to Europe, Zimbabwe spends over $100 million in local currency: roughly $45 million to subsidize cold storage commission losses, $35 million for veterinary expenses, and more for foot and mouth control fences and other activities (Rowan-Martin and Cumming, pers. comm., 1988). However, to support a safari industry which brings about $7 million in foreign exchange, the government invests about $1 million. The difference in the return of foreign currency for the cattle and game investments is over twenty-fold. Game meat in Zimbabwe is nearly all sold as local rations near the ranches. It is priced at two thirds the cost of cattle. This local protein source is extremely important, as a linear increase in

poaching on the ranches is observed with decreasing availability of ration meat (e.g., when exported).

Regardless of economics, fewer cattle are available for food at a local level in Africa because people increase faster than the herds, carrying capacity is eroded, every effort is made to export, and marketing infrastructure restricts flexible, rapid, and responsive distribution. The growing disparity between people and cattle is easy to document. For example, the ratio between cattle and people in Tanzania has decreased from 0.87 in 1948 to 0.71 in 1978, while per capita meat consumption declined from 10 to 7 kilograms per year over the same period, compared to 99.6 kilograms per bushman and 38 kilograms per capita in Kuwait (FAO, 1966-1984). The Tanzanian demand for meat (at very conservative levels, two thirds that of Kenyans and one tenth that of bushmen) was about 193,000 metric tonnes by 1982, with a production level of 139,000 metric tonnes.

Beyond the economic, cultural, and environmental costs of domestic livestock, a much more intriguing and insidious effect of the policy of replacing game meat with livestock is emerging in recent research on human nutrition. Humans, as we know, must consume protein, about 50 grams each day. However, several of the amino acids essential in our diet are found primarily in animal products, and many tests show the need for animal protein (including milk) as a regular supplement to food from vegetative sources, even legumes (Hunt, 1988). However, the animal protein

source produces another dietary dilemma -- the ingestion of either "good" fats or "bad" fats. Bad fats (saturated) are deposited around tissues and waistlines and have been linked to cholesterol-related heart disease -- the major killer of North Americans and Europeans. The good fats are inside cells and their membranes are essential for their construction and function. Although not in the "bad fat" category, unfortunately short-chain unsaturated vegetable fats do not help cell construction and function. The required long-chain polyunsaturated fatty acids are obtained through meat consumption. This biochemical esoterica is significant in that long-chain unsaturated fatty acids constitute 50 to 70 percent of the brain, where it is incorporated ten times faster than vegetable-source precursors. Crawford (1975) said that "Diets deficient in essential lipids produce an irreversible reduction in brain size and an irreversible impairment of the learning ability". These effects of nutritional deficiencies are particularly significant in childhood, and Hunt (1988) links deficiencies in animal protein and fats to retarded development of children in Lesotho.

Much of the developed world is threatened by excessive consumption of saturated fats. The U.S. Surgeon General considers the reduction of saturated fats in the diet as the first priority in his Report on Health and Nutrition (USHHS, 1988). This knowledge has reduced beef's share of the meat

market in the United States from 41 percent in 1971 to 31 percent in 1987, a reduction of nearly 25 percent (Chadwick, 1988).

The predominance of saturated fats in cattle reflects the way cattle process forage into fat. How can animal protein be provided, cholesterol reduced, and long-chain fatty acids be incorporated from any available source? Domestic animals have from ten to twenty times more fat than wild game. Furthermore, Crawford (1970) shows that meat from wild game, when compared to cattle, contains from two to twelve times the percent of polyunsaturated fat.

We suggest two strategies:

- Hunt (1988) said that "To emphasize game as an essential element in diets of low-income indigenous people could have staggering implications for a nation's development." This conforms with Asibey (1977), who said that people prefer wild meat and will continue to attempt to supply it. He concludes that the "role of bush meat production be recognized in development plans and patterns of land-use, if it is not ultimately to fade away." It appears that people were doing what was best for them before modern livestock husbandry systems were imported. We do not advocate a return to universal hunting and gathering or suggest that cattle have no place, but they may have a different place, as might wildlife in a more integrated development strategy.
- Supplying wild meat to the increasingly health conscious, lucrative markets of the developed world makes sense because it generates foreign exchange, and the high technology required to maintain domestic stock is costly.

4.6.2 Ecological Considerations Favoring Wildlife Utilization

This review relates the five major ecological determinants of rangeland productivity, diversity, and resilience (described in 4.2.2) to characteristics of African wildlife. It clarifies

the rationale for commercial uses of wildlife and points to specific tactics.

In many native rangelands and forests, wildlife can make more efficient use than cattle of the native forage spectrum. High production can be sustained without reducing the carrying capacity of the range. Comparisons between wildlife and livestock primarily from research in East and southern Africa support these conclusions.

Biomass. The total weight of wildlife is on average seven times greater than cattle weight in similar habitats, or that of sheep and goats in areas denied cattle by tse-tse fly (Talbot et al., 1963).

Productivity. Productivity (a better measure than biomass of harvestable meat each year) studied in the low veldt of Zimbabwe on a ranch with thirteen harvestable wild ungulates, was over four times that of domestic livestock (Dasmann, 1964). In addition to offtake, other indicators of efficient production confer a large advantage to wild animals. For example, oryx have a higher percentage of meat to body weight than cattle (57 compared to 50 percent), and calve a year earlier at a five-month interval. Data from Kenya suggest that gazelle and impala produce about 30 percent more meat in dressed carcass weight than cattle because of their comparative efficiency in converting forage to protein (Blankenship, Texas A&M, in press). Domestic

cattle have less than one half the daily weight gain of eland (Jaffe, 1976).

Resource Partitioning. Resource partitioning is exhibited by wild species, which can thrive on portions of the vegetation spectrum which are either unavailable to livestock (for example, out of reach) or unpalatable. In the Gir woodlands of India, during the dry region when forage becomes dry, fibrous, and scarce, wildlife could browse leaves of woody plants with 12 percent protein, while cattle were obligate grazers on grasses with 3 percent protein -- below the 7 percent minimum required for maintenance (Berwick, 1976). A community of wild African ungulates -- often 15 species as varied as giraffe and gazelle, consumes a much larger spectrum of the vegetation, thereby capturing more energy for production. Giraffe browse the tops of thorny acacias, while gazelle eat the fresh shoots of short, rhizomatous grasses made available by the lawnmower activity of course grass feeders such as zebra (See Figure 4-1 and Table 4-1). Even within one vegetation stratum (for example, grass), adaptations permit wider use.

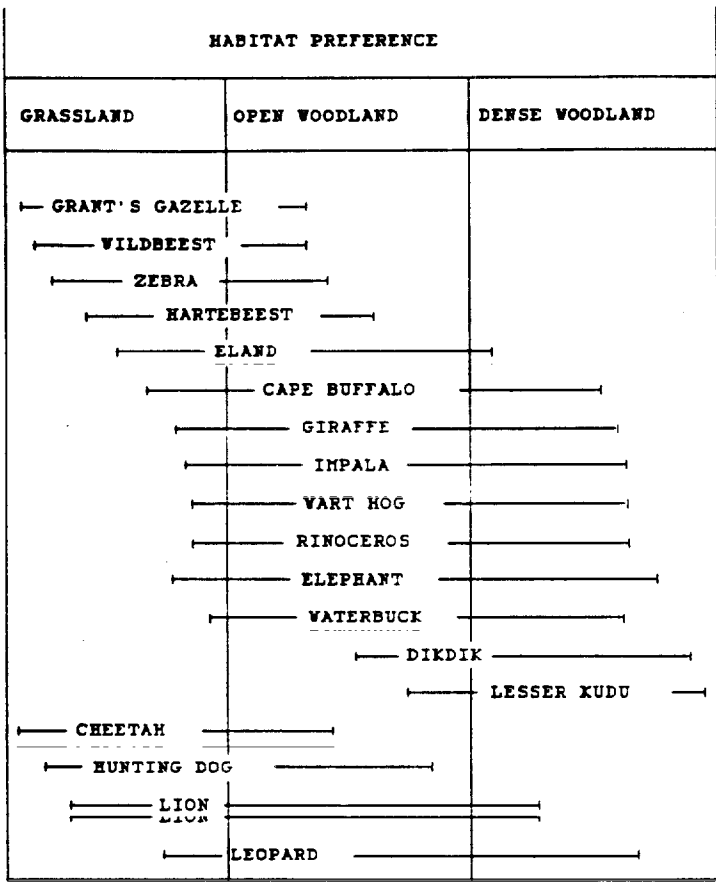
On the Buffalo Range Ranch to be described in the next chapters, Taylor and Walker (1978) found that wildlife consumed more of the total herbaceous vegetation (43%) than did cattle (28%) and twice the number of grass species. Such a division of capabilities and preferences works in various ways. Animals can eat similar forage but live in different habitats, feed at

different heights in the vegetation, while different species feed in an area at different times of the year. Each species can consume a characteristic proportion of browse, grass, forbs, or fruits from specific species. Many investigators have measured such differences in diverse ungulate communities around the world (Berwick, 1976; Lamprey, 1963; Sinclair, 1985). Fine distinctions in plant structures consumed (e.g., stem, leaf, and sheath of a grass) can further distinguish between animal species since the nutritional content and digestibility varies for each part.

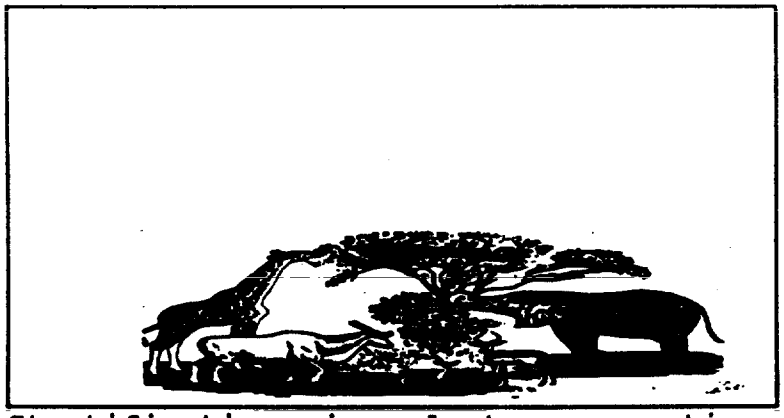
Physiological Adaptations. Physiological adaptations to local environments are exhibited by numerous wild species. Wild animals exhibit extraordinary adaptations to dry areas (except for camels, which do not possess wildlife's tolerance to tse-tse). Oryx have one quarter the water requirements of cattle, permitting a much wider use of forage resources away from expensive water developments. Some wild species, including oryx and gazelle, do not require any freestanding water if none is available. Eland require some shade, and turn over water nearly twice as fast as oryx, which (like hartebeest) reflect over 40 percent of the incident radiation (Field, 1979). In contrast, even the most-adapted local breeds of cattle, herded by the hardiest African pastoralists, require some regular water. Although local Zebu cattle appear to be able to reduce metabolism (at a cost to productivity) and range further than imported breeds, they do not compare with the capabilities of hardier

wildlife species to survive drought by physiological or behavioral means.

Figure 4-1. Habitat preference and food preference based on frequency observations along transects in two areas of Tanzania (adapted from Lamprey, 1963).



% SELECTION OF FOOD PLANTS		
GRASSES & SEDGES	HERBS	SHRUBS & TREES
90.67	4.00	5.33
94.48	3.45	2.07
92.57	5.53	1.90
96.25	2.50	1.25
70.18	8.77	21.05
93.64	1.21	5.15
0.83	1.10	98.07
92.62	1.23	6.15
88.32	9.28	2.40
38.00	9.33	52.67
12.47	1.29	86.24
95.14	0.81	4.05
17.95	2.56	79.49
66.67	4.75	28.58



Stratification in plant consumption. (Desmann, 1962.)

TABLE 4-1 The importance of ecology in range management – some relationships between principles, processes, & management activities.

PRINCIPLES	SELECTED PROCESS	SELECTED MANAGEMENT ACTION(S)
Disturbance and Succession	Relative changes in productivity, stability, and diversity.	o Evaluation of range condition
	Corresponding physical changes in soil chemistry and development, albido, and erosion	o Rehabilitation measures o Manipulating class of stock (e.g. browser/grazer) to direct range modification
Herbivory/Defoliation	Energy transfer	o Manipulating of species to maximize secondary production
	Efficiency, species	o Manage grazing intensity and overuse (fence, salt, herding, etc).
	Ecological efficiency	
Co-evolution	Seasonal phasing of plant species use by animals	o Control of noxious/poisonous plants o Selection of animals tolerant of plant defenses o Rehabilitation of selected forage species to maximize revegetation (establishment)
Soil Structure	Primary production, infiltratory erosion	o Selection of grazing system to control compaction, ground cover o Grazing control measures (fence, salt, herding, etc.)
Cycles & their interactions	Plant/animal population changes, feedback in the system, habitat change	o Park/Preserve management o Fire/herbivory management o Resource banking strategies (e.g. forage, capitol) o Investment strategies

Explanation of Numbers in Matrix of Table 4-1.

Problems Afflicting Efforts to Ranch Wildlife in Africa, 1960-1975

1. Hippos became shy and were difficult target in the water if culled during the day; they were lost and scavenged by hyena at night.

2. Elephants were very difficult to see in dense Commiphora bush and consequently could not be killed in the entire family group required for humane culling.

3. At Tsavo/Mkomasi, the efficiency of kill was enhanced with an airplane to spot and helicopter to drive game, but availability of aircraft was low and cost high.

4. Immobilizing elephants with Sucostrin is inhuman (muscle paralysis with awareness) and getting whole family impossible -- when went to shooting it was more efficient (1.1-1.4 bullets/kill) as with the Murchison kill of 12/minute.

5. Not enough lechwe to sustain necessary harvest (less than 2% of abbettoirs' capacity was shot) compounded by difficult, swampy terrain.

6. Elephants became very shy with high incident of poaching.

7. Plains game (primarily gazelle) became shy and dispersed with shooting. Not enough animals in dry season to sustain necessary harvest.

8. Gazelle become very shy with shooting and moved or migrated out of area.

9. Buffalo became very shy with shooting.

10. Found that canned meat was excellent product, very feasible, but the area (Grumeti) became incorporated into National Park.

11. Night shooting only effective on moonless nights and found round-up to boma for slaughter was effective, except for Thompson's and Grant's gazelle, impala and Coke's hartebeest which would not be herded.

12. Because of migration and seasonality, only got 2% of harvest achieved (except for zebra); the eland quickly leave area with shooting and are very mobile.

13. Could not round up without bruises/injuries, particularly to wildebeest which become vicious.

14. Grant's gazelle in project left area with much shooting, though Tommy were easy.

15. Although no effect of long-term shooting harvest on impala behavior/kill rate, snare trapping not very effective (22% accident/predator loss).

16. Good shooting is labor intensive and demands high skill and stamina.

17. Rifle barrel distorts with heavy shooting, losing accuracy.

18. Wildebeest and impala can become vicious and bruise/injure others in boma when rounded up.

19. Thompson/Grant's gazelle, Coke's hartebeest and impala impossible to round up to boma with helicopter; similar problems with lechwe.

20. Needs 50 man-days to erect wing trap/boma for chopper round-up.

21. Got 6 animals a day by trapping and 17 by shooting (still only 20% by quota).

22. Got average of only about 40% of desired quota (Range was between 12% for kob; 94% for waterbuck).

23. Fixed location of expensive facility which could not respond to depletion of nearby sources of elephants on which it depended.

24. Because of legal restrictions for roads, size of trailer/abattoir had to be 1/2 capacity necessary to process/transport quote/day.

25. Though tried to integrate Hazda hunter-gatherers, area was too remote to process and transport meat.

26. Parasite loads generally acceptable; e.g. if less than 5 cysts can sell (3% of carcasses).

27. Zebra fairly cyst-free (3% of carcasses condemned) though 23% of gazelle and 21% of wildebeest were unacceptable (none of gazelles near Moshi; therefore, levels vary).

28. In swampy area 23& of carcasses condemned.

29. Offal disposal problem solved by dumping in bush for vultures in daytime as they sterilize cysts with high body temperature; if dumped too late, hyenas/jackals eat offal at night and tapeworm spreads.

30. Had to bypass existing abattoirs with own system due to antagonism of cattle ranchers.

31. Cattle ranchers threatened butchers who accepted game.

32. Biltong in best restaurants is a good product but too labor intensive.

33. Meat meal gets around any hygiene problems but only fetches 26% of fresh meat value and 59% of world meat price.

34. Could get 2/3 more than beef in butcher shop.

35. Exports probably precluded because of foot and mouth regulations, although zebra are OK and desirable in France and Belgium.

36. Skins very valuable -- e.g. about 8 for wildebeest and much more for zebra.

37. National Parks Department would not allow meat transport to nearby market making long trip less feasible.

39. Successful harvest/market project area became incorporated in National Park.

40. Although generally successful project, environmental community was implacably opposed.

41. Poaching increased and hurt possible offtake when area de-gazetted for wildlife use.

42. Resistance by local ranchers/cattle industry.

43. Low esteem of local market for game meat.

44. Opposition of environmentalists.

For example, some wild species can satisfy all of their water requirements by browsing at night on leaves which absorb moisture when cooling increases moisture in the air. In similar dry environments, cattle would suffer high predation (Taylor, 1969). Furthermore, a Kenyan study indicates that wildlife are nearly twice as efficient as cattle when digesting the same amount of similar forage (Blankenship, Texas A&M, in press). Twice as many gazelle or impala could exist on the same amount forage consumed by an equivalent weight of cattle. This is a reflection of a much more efficient digestive process, since the smaller animals must consume relatively more to feed a higher metabolism.

4.7 Status of Game Ranching

4.7.1 Meat Production -- Cattle and Wildlife

In the Zimbabwe study to be described later, the real costs of cattle to the environment only became evident after several drought episodes. Even in subsequent periods of adequate rain after each dry year, cattle performance as an environmental indicator began to slip, for example, calves produced per female declined by one third and weight gain decreased nearly 50 percent (Child, 1988). The reasons are suggested by computer simulation runs (see Chapter 6) which show a decline in carrying capacity on a cattle area in the low veldt of Zimbabwe, with very slow recovery after the dry years. In contrast, the effects of drought on carrying capacity and on immediate recovery in the wildlife area were not as severe. This is ultimately expressed in the finances of the ranch. Following a very serious drought, raising cattle was no longer profitable, and all range condition indicators became unfavorable (Taylor and Walker, 1979; Child, 1988). All indicators in an adjacent game-only section were stronger, including forage production (plant cover actually increased).

Commercial cattle ranchers in Zimbabwe perceive these post-drought indicators and are committing all or part of their operations to wildlife utilization at the rate of 8 percent of the commercial ranches per year (Child, 1988). The Republic of South Africa has about 5,000 commercial wildlife ranching enterprises (P. Small, 1988, pers. comm). Although data are

still being collected, perhaps the best indication of the potential for using wild products lies in the increasing commitment of resources by those who have the most to gain or lose -- the farmer and rancher. One feature of the success of the large commercial properties is that the approaches have yet to spread to the commercial areas so important to wildlife resources in southern Africa.

In contrast to southern Africa, game culling and ranching in East Africa is much more variable (See Table 4-2). The reasons for the successes in southern Africa and the problems in East Africa are not yet clear. They appear to be more political than biological, e.g., ephemeral policies, control over investments, land tenure, etc.

One ranch which has profitably harvested wildlife is Wildlife Research and Ranching (WRR) in Kenya, a lone survivor in the regional game industry. It has been servicing the lucrative restaurant market in Nairobi (which it had to develop) for over nine years. During this period cattle and sheep were reduced on the property by more than half to 1,100 head and wildlife maintained at about 1,500 head. At prices 50 to 100 percent above beef, sales indicate a gross income double that of comparable ranches and a net nearly ten times that of nearby ranches. However, these figures are confounded by some capital subsidies such as fencing, the restrictions on hide sales, and a drought which resulted in an over-harvest, and therefore

increased game sales. During this drought the environment did not suffer nearly as much on the mixed game and cattle operation (WRR) as it did on adjacent cattle ranches, which suffered over 50 percent cattle losses. These analyses should be updated through the subsequent dry and wet years.

TABLE 4-2 Problems afflicting efforts to ranch wildlife in Africa, 1986-1975.

Species and Location of Example

Issues	Kenya			Uganda		Tanzania				Zambia		So. Rhodesia	
	FAO/ Kajiado	Galana	Tsavo	?	Q. Eliz.	Kilimanjaro	Serengeti	Lollando	Yalda V	Lochinvar	Luangwa	Henderson	?
Harvesting													
1. Shyness					1,6,9	8			7				15
2. Difficult Terrain or Target		2,16	3		1					5			16
3. Competition with Predators/ Scavengers					1								15,18
4. Other Behavioral	11,13,14	2				8		12			4		
5. Technology	19,20,21 22,29		4				18			5	4,20,21		17,18
6. Accurate Counts/ Offtake Calculation	22			23					7				
Preparation & Processing													
7. Abattoir	24									23			
8. Cooling/Transport (bone temperature)									25				
9. Timely Dressing													
10. Dustfly-free environs													
11. Staff Hygiene													
12. Water Availability													
13. Veterinary/Meat Inspection	26					27		27		28			
14. Offal Disposal	29												
Marketing													
15. Competition with Cattle						31						42,43,30	
16. Credibility/Dependable Supply	32												
17. Presentation of Meat	32,33												
18. Price	33,34												
19. Public/Animal Health	29,35,36							36					
20. Other Products													
Political/Regulatory													
21. Competition with Cattle					31							42,43	
22. Obstruction by Resource Agencies							38				44		
23. Objection of Environmentalists	41												
24. Conflict with Poaching	42												

*See accompanying pages for explanation of each number in the matrix columns for each project cited.

4.7.2 Safari Hunts

Commercial safari hunting is often viewed as a characteristic activity of colonial East Africa, but is a relatively recent use of wildland resources in Zimbabwe. Actually, nine countries from the Sahel to South Africa now support safari hunting, including Central African Republic, Cameroon, Somalia, Tanzania, Botswana, Namibia, and the Republic of South Africa. In Zimbabwe, sport hunting began in 1961 on the Department of Parks and Wildlife Management controlled hunting areas. However, the profitability and expansion of commercial hunting blossomed as ranchers developed mini-hunts in conjunction with game hunting in safari areas, and as landowners became responsible for management and use of wildlife resources on their property. Hunted wildlands amount to about one fifth of the country, largely on the 43 percent of Zimbabwe that is commercially run and privately owned, on 60 percent of the Parks and Wildlife Estate (which constitutes nearly 13 percent of the country), and on some of the 42 percent of the country in communal farming.

Hunts focus on plains game of the ranches (zebra, kudu, impala, etc.) and big game on state and communal areas (lion, buffalo, elephant, etc.). A typical 21-day big game safari can cost $25,000 exclusive of airfare. A similar hunt is more expensive in Tanzania or South Africa. The market is not close to being accommodated. Quotas are established by the Department

based on a census and sophisticated offtake models. For example, trophy hunting dictates (roughly) less than 0.5 percent of a given population of elephant can be taken, 2 percent of most other ungulates, and 8 percent of large cat populations. These rates will ensure a sustained quality (large trophy) hunt. Direct revenue earned by the government from trophy safaris is about Z$0.60 per hectare for a total of about Z$1 million, and Z$0.25 per hectare from the communal lands (about Z$2 million) (Cumming, 1988). The potential of tribal lands is somewhat reduced because they have human settlements and associated uses such as intensified pastoralism, which increasingly conflict with safari potential.

Safaris, however, are by far the most lucrative actual or potential income generator on tribal lands with big game. This is extremely important because of the low productivity of subsistence grain farming and vulnerability of livestock to regular drought. Maize and millet are about one tenth as productive as on commercial farms, and do not fulfill the subsistence requirements of a family of seven (ARDA, 1983). Inputs such as fertilizers or grain purchases require cash, which can be supplied by income from wildlife ranching. Communal stock raisers lost most of their herds twice this decade while severely degrading the range and lowering its future carrying capacity. Wildlife would be an environmentally benign economic buffer.

4.8 Summarizing -- a Rational Transition

For the rancher, the economics driving the transition from cattle husbandry to wildlife exploitation in Zimbabwe are rather dramatic on the few ranches where records have been maintained. In the southern low veldt, profits for the Rosslyn Ranch track the increase in safari hunting -- Z$0.36 per hectare in 1968-69 (1986 dollars) to Z$1.90 per hectare in 1973. The proportion which safari hunting contributed rose from 2 to 75 percent of the income. Buffalo Range Ranch enjoys a profit from wildlife over three times that of cattle. Game meat sales contribute to about one third of the income, and trophies, two thirds (Child, 1988). The profits from big game hunts on communal lands are evenly split with the local tribal administrative units. More significantly, wildlife earnings are stable (Style, 1988). Annual harvested game meat production is about two thirds that of cattle. Profit from wildlife during two of three consecutive drought years contrasted with large losses all three years on the cattle section.

In both Kenya and Zimbabwe variations in markets for game meat, hunting, and beef respond to political stability, foreign perceptions of recreational value, security, product quality, and many other factors. In this respect, much of Africa is similarly influenced by market perceptions as yet poorly understood or controlled. Two years of losses in safari revenues led to net ranch losses as a result of Zimbabwe's security problems in 1980

and 1981. A sudden change in wildlife policy stopped all on-ranch hunts in Kenya during 1987-1988, including weekly harvest for meat on the WRR ranch. In both instances cattle provided a financial buffer. Furthermore, livestock serve many functions in Africa which are culturally significant and unlikely to disappear. The studies do show that wildlife can be more profitable, afford a buffer during climatic variations, and are more conserving to the environment upon which they depend. Additionally, there is much of Africa which is precluded from cattle use by the tse-tse fly. For example, 38 percent of the region which includes Angola, Botswana, Mozambique, Tanzania, Zambia, and Zimbabwe is tse-tse infested and occupied by game which can be managed for various uses (or protection) (Cumming, 1988).

However, unless the value of conventional agriculture on marginal lands increases and productivity losses are arrested, the poverty (twenty-three countries with per capita incomes of less than $400) and human mortality increasingly seen today will not be reduced.

The use of IPT as a planning aid and game ranching are attempts to direct land use away from monoculture to multiple uses in order to buffer both resources and users in the marginal African range environments. It is a move to understand, co-opt, and adopt traditional land-use practices by rendering them income-producing -- a notion which goes beyond subsistence in

poverty. Ultimately, the dependency on any single land use is a prescription for vulnerability. Tourism, cattle, safari hunting, cropping for meat and other uses can be individually oversold. Each has been proven profitable. A dynamic mix can be sustainable as well.

The example of using IPT to compare wildlife and cattle influences on range condition illustrates factors which could contribute to more informed management. The potential of wildlife utilization and IPT are the subjects of the remainder of this book.

Chapter 5

USING IPT FOR PLANNING AND MANAGING RANGE, LIVESTOCK, AND WILDLIFE RESOURCES

		Page
5.1	Introduction	206
5.2	Understanding Goals, Problems, and Questions: the Workshop Results	207
	5.2.1 Macro Level Workshops	207
	5.2.2 Local Level Workshop	211
5.3	Schematic Model of a Range, Livestock, & Wildlife System	222
	5.3.1 Overview	222
	5.3.2 Range Submodel	222
	5.3.3 Livestock Submodel	237
	5.3.4 Wildlife Submodel	250
	5.3.5 Ranch Accounting	264

5.1 Introduction

Previous chapters have described the methods used during various stages of implementing Integrated Planning Technology. These descriptions have attempted to impart an understanding of the IPT process, as opposed to a specific problem or system. Chapters 5 and 6 focus on the use of IPT methods as applied to range, livestock, and wildlife systems in Southern Africa.

We envision two broad user groups, not only of the software, but of the method and results. The first could be broadly defined as policymakers and planners -- individuals, or groups of individuals, private or public, who have some impact on range use. They may be individual ranch managers who are in daily contact with the resource and need to better understand the implications of their management decisions. Or, they may be government officials who need to understand the potential and problems of the range in order to determine policies.

The second group includes range science students at all levels. In addition to students studying for a degree or certificate in an academic program, range scientists may also find this information of use in setting research agendas and priorities. This group includes anyone who has an interest in better understanding the patterns and processes of range ecology and management.

5.2 Understanding Goals, Problems, and Questions: the Workshop Results

5.2.1 Macro Level Workshops

Two of the workshops reported here were held at a macro level. The first was conducted for and sponsored by the U.S. Agency for International Development (AID) in Washington. The workshop had nine working groups, two of which focused on range and livestock, and plant, animal, and wildland ecology.

Another workshop was held in Gaborone, Botswana, as part of that country's National Conservation Strategy (NCS), an exercise sponsored by the International Union for the Conservation of Nature and Natural Resources (IUCN). The results reflected different purposes for the two workshops. The AID workshop was intended to help identify research needs, and to start and guide the model development process for sectors in which AID is involved. The workshop in Botswana however, was to help the authors of the NCS link up with authors of other chapters to provide an integrated analysis of systems under consideration. The longer term purpose of both of these activities was to "assist decisionmakers with projections of the financial, growth, and conservation consequences of policy and programme proposals (IUCN, 1986)."

The results of these first two workshops reflect our own use and evolution of the IPT methodology. In the AID workshops we did not ask the groups to pose their key questions. In the

Botswana workshop, we did not ask the participants to identify what they thought the goals were. We now know that either omission is a mistake and include both in all workshops. We will not cover all the details of the macro level workshops, but will report the goals, issues, and key questions as appropriate. Chapter 3, Section 3.3 explains the workshop methods in detail.

AID Workshop: Goals. The goals identified in the AID workshop were specific to work in the countries where the Agency is active.

Range and Livestock

- Enhance the subsistence of human residents.
- Maintain the widest resource use options available to future residents consonant with other goals.
- Income growth.
- Enhance socioeconomic choices.
- Enhance or make possible leisure time for residents.
- Maintain traditional cultures, technologies, and uses which complement other goals.
- Use sector to help maintain national stability and security, and to foster national goals.
- Enhance the acceptability of useful technologies.

Plant, Animal, and Wildland Ecology

- Maintain the biological diversity of all taxa by maintaining the variety of habitats, species, and genetic variability.
- Mitigate environmental impacts of development processes.
- Explore methods to place values on wild resources.
- Expand the basic knowledge of wild resources.

AID Workshop: Issues. Numerous issues were defined in both working groups. In the plant, animal, and wildlands group however, the issues defined were not entirely suitable for simulation methods. We later discarded some of their results because the discussion was not useful for our purposes.

Range and Livestock

- Land tenure patterns including absentee ownership, communal ownership, and migration.
- Land capability and limitations.
- Overgrazing and overpopulation of livestock.
- Climatic variations and limitations, especially drought.
- Availability of genetic material.
- Quality and distribution of water.
- Knowledge, risk aversion, and acceptance of technology.
- Access to capital.

Plant, Animal, and Wildlands Ecology

- Valuation of wild resources, particularly biological diversity.
- Lack of appropriate criteria for cost/benefit analysis and communication of issue.
- Irrelevant academic curricula with respect to development issues and foreign conditions.
- Geopolitical versus ecological boundaries.
- Lack of acceptance of sector and career paths for individuals.
- Poor knowledge and attention paid to animal damage control and wildlife diseases.

Botswana NCS Workshop Participants were split into three groups, cattle, wildlife, and macroeconomics. No key questions were reported for the macroeconomics group.

Cattle Issues

- Overgrazing and range management.
- Water supply for cattle and demand for boreholes.
- Disease control.
- Inadequate implementation of legislation.
- Growth of human and cattle populations.
- Marketing.
- Skewed ownership patterns.
- Conflicts between cattle and wildlife for range resources.

Wildlife Issues

- Effects of drought on wildlife populations.
- Subsistence and commercial poaching.
- Human encroachment into wildlife areas.
- Physical barriers to the movement of wildlife and access to water and forage.
- Economic uses of wildlife.
- Fragmentation of wildlife areas.

Macroeconomic Issues

- Unemployment.
- Lack of rural development.
- Lack of diversification in the economy.

- Small size of the domestic market and reliance on imports.

Cattle Key Questions

- What is a sustainable national herd size?
- How do various incentives and disincentives to production affect the management of herds and the range?
- What is the effect of drought or good rains on range condition?
- What is the actual stocking rate and herd size under various policies?
- What is range condition under various policies?

Wildlife Key Questions

- What is the effect of drought on wildlife numbers?
- What are possible management responses to drought, both governmental and non-governmental?
- Under various policies what are the stocking rates?
- What is the production of forage under various policies in wildlife areas? Is this production sufficient?
- Which animals are poached, and how does this poaching affect wildlife populations?

5.2.2. Local Level Workshop - Chiredzi, Zimbabwe

In an effort to conduct a rigorous test of the IPT methods, we identified several places in Africa where there were reasonably long times-series data for livestock and/or game projects or operations. The longest and most detailed data base suitable for this task was a commercial livestock and game ranch at Buffalo Range, Zimbabwe. We traveled to Zimbabwe gather to

information on livestock and game ranching in general, and from Buffalo Range Ranch in particular.

The Wildlife Producers Association of Zimbabwe arranged for us to conduct a workshop near Buffalo Range, in Chiredzi. This workshop was extraordinarily fruitful; we learned much from the discussions with participants about actual operations in the area, the decision-making processes, and the difficulties and rewards of ranching in the low veldt of Zimbabwe.

The workshop participants represented a spectrum of perspectives and positions. Twelve persons attended, some driving as long as two hours each way in order to participate each day. Livestock ranchers, wildlife ranchers, as well as ranchers with mixed operations attended, in addition there were veterinarians or vet students, a professional hunter, and representatives of one of the largest agricultural concerns in the country. Some people represented conservative viewpoints, while others were quite progressive. All had a commercially oriented viewpoint, and in one way or another, directly influenced the use and management of the range resource. These individuals controlled close to 500,000 acres.

Goals

- Make money.
- Maintain long-term ecological productivity and/or improve it.
- Maximize diversity of flora and fauna.

- Rehabilitate systems to prior diversity and quality.
- Satisfy local demand for consumable resources.
- Maintain relevant technology and production systems.

Issues

- Drought.
- Veldt (range) degradation.
- Greed and/or bad management.
- Politics.
- Poaching.
- Education of farmers to understand the systems they manage.
- Marketing and lack of markets.
- Lack or information and data.
- Long-term tenure and security and resulting short-term planning.
- Uncertainty with regard to payoff and investments.
- Lags in scheduling for government pricing.
- Rising inputs costs.
- Lack of foreign exchange and scarcity of goods.

Reference Modes. Reference modes for seven indicators were drawn by the workshop participants. The group decided that time period for these reference modes was about the period of a drought cycle. Drought periods are indicated where appropriate on the reference modes shown in Figure 5-1.

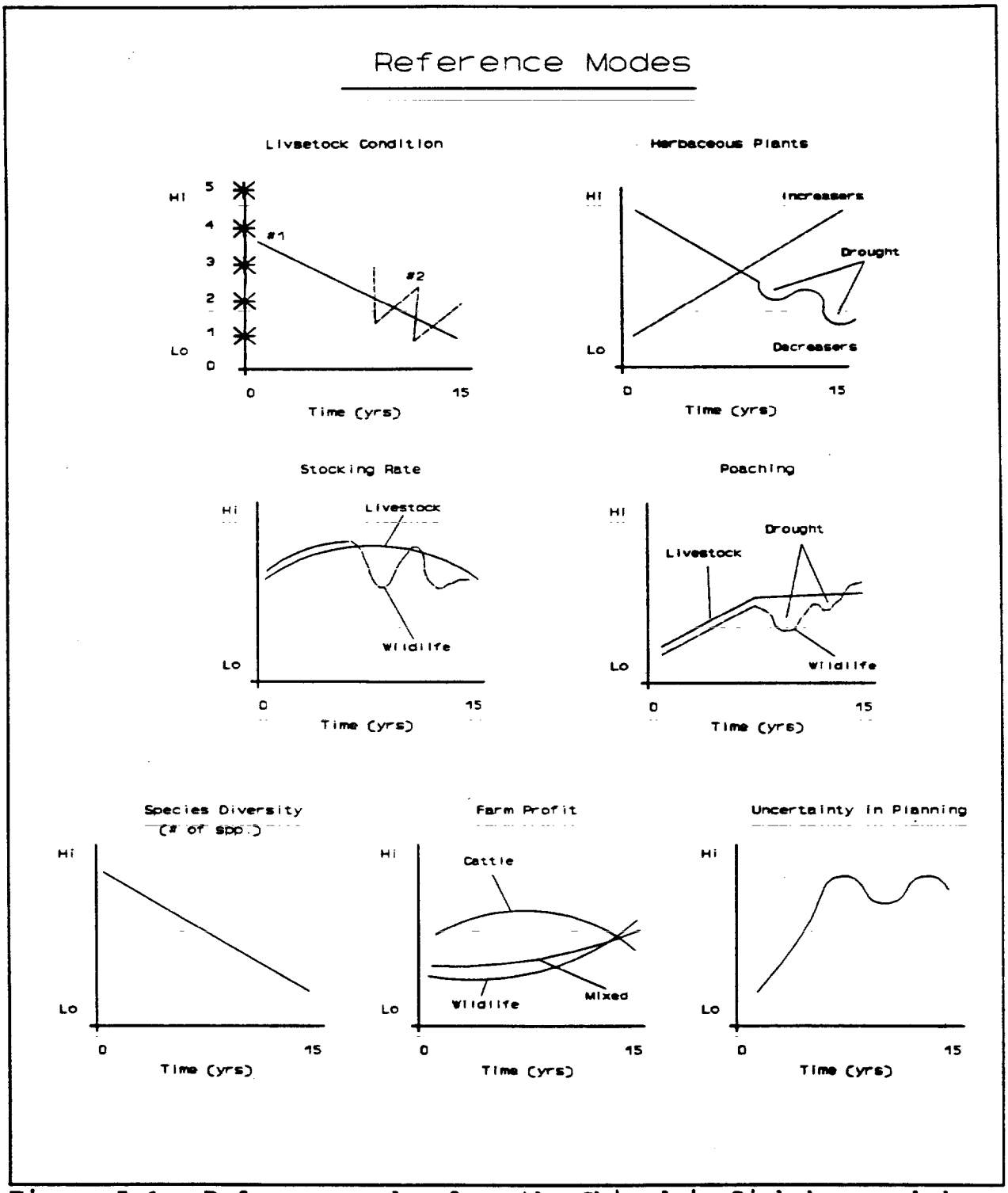


Figure 5-1. Reference modes from the Chiredzi, Zimbabwe workshop. These diagrams depict the behavior of key system indicators as perceived by participants.

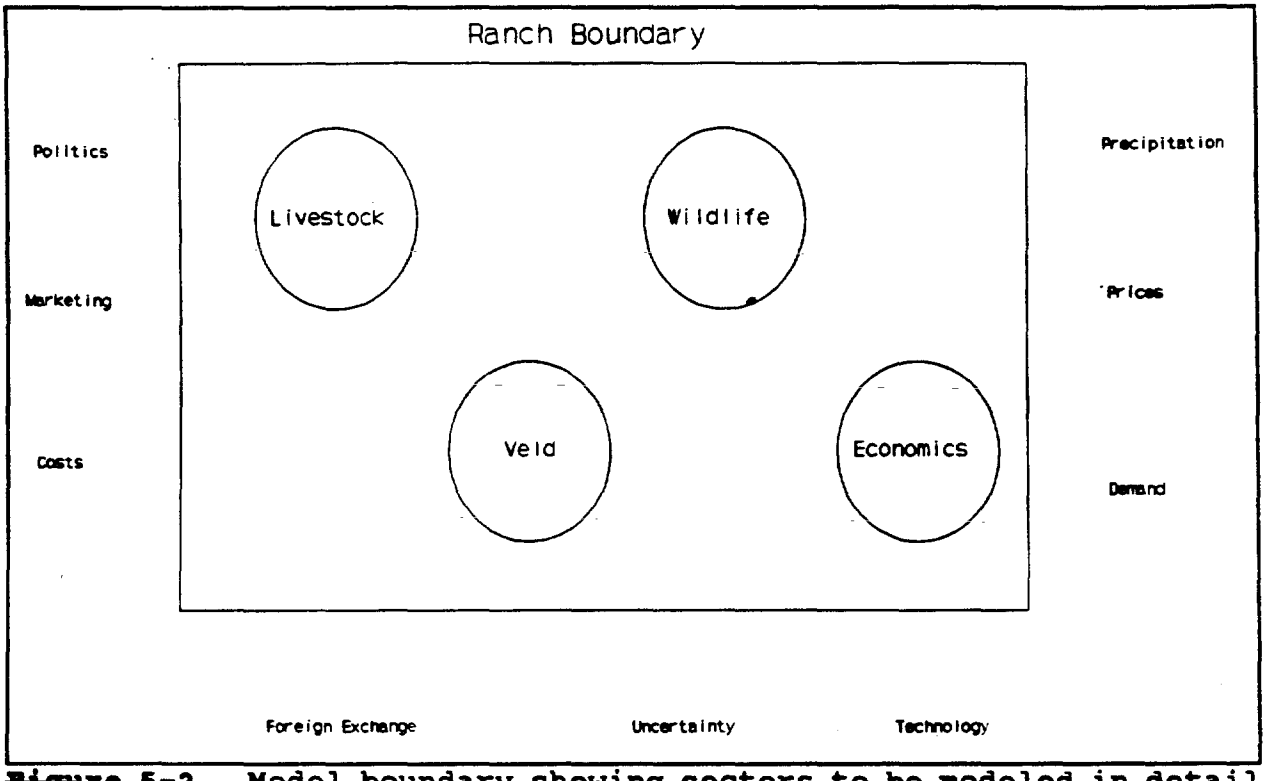


Figure 5-2. Model boundary showing sectors to be modeled in detail (circles), and factors to be modeled as external to the ranch or implied (outside the box).

Key Questions. Eleven key questions were posed by the participants. Not all are suitable to analysis by simulation methods, however we felt it was better not to constrain the group's contributions, but later filter out questions, problems, and issues which can be addressed. Some of the questions posed can be answered by basic research.

- What is the break even point for a given investment, and when will it occur?
- What is the most profitable age to use/takeoff animals?
- What are the criteria for offtake -- age, disease, forage, etc.?

- Is it more profitable to change animals to suit vegetation, or vegetation to suit animals?
- Are there more productive or profitable alternatives to existing systems?
- What level of anti-poaching enforcement is cost-effective?
- What kind of information is most important to achieving the goals?
- What management policies (fire, reseeding, grazing system, etc.) are best for existing forage/habitat types?
- What is the best/most profitable stock (cattle) marketing strategy?
- What is the best/most profitable game marketing strategy?

Model Boundaries. Several simple boundaries were placed on the model and the analysis for which it would be used. First was the spatial boundary. All group members agreed that the model should be confined to the limits of a typical livestock or wildlife ranch characteristic of the low veldt. Figure 5-2 shows these boundaries, the sectors which should be modeled in detail, and some of the factors which it was agreed should be either excluded or modeled simplistically. For example, a detailed livestock model should be developed which would include significant feedback and processes. Precipitation would have to be included, but it could be randomly determined or use actual data. Foreign exchange could be modeled implicitly rather than explicitly.

Variable Lists and Diagrams. The variables to be considered for each sector were listed (except economics, which was to be a simple accounting model). We then took these lists and structured them to determine how they should interact. The

variables were determined from continual reference to the work that had already been done: goals, problems, and key questions.

Livestock Variables

Head of stock
Slaughter
Sales
Mortality
Sex ratio
Theft/snare deaths
Snared slaughters
Predator caused mortality
Mineral supplements
Natural forage
Pen fattening
Purchase of animals
Dips
Vet costs/medicine
Births
Performance
Age at slaughter
Weight at weaning
Calving rate

Wildlife Variables

Populations by species
Predators
Ungulates
Veldt types
Births
Poaching
Water distribution
Natural mortality
Safari hunting
Sport hunting
Culling
Live sales
Live purchases
Migration/fencing
Food preferences
Prey preferences
By products
Demand for products
Information
Management quality

Veldt Variables

Effective rain
Litter basal cover
Species composition
Stock of plants
Runoff
Topography/slope
Water distribution for forage utilization
Water quality
Fire and frequency
Forage consumption -- grazing and browsing
Grazing systems
Competition by harvester termites
Soil compaction
Habitat types

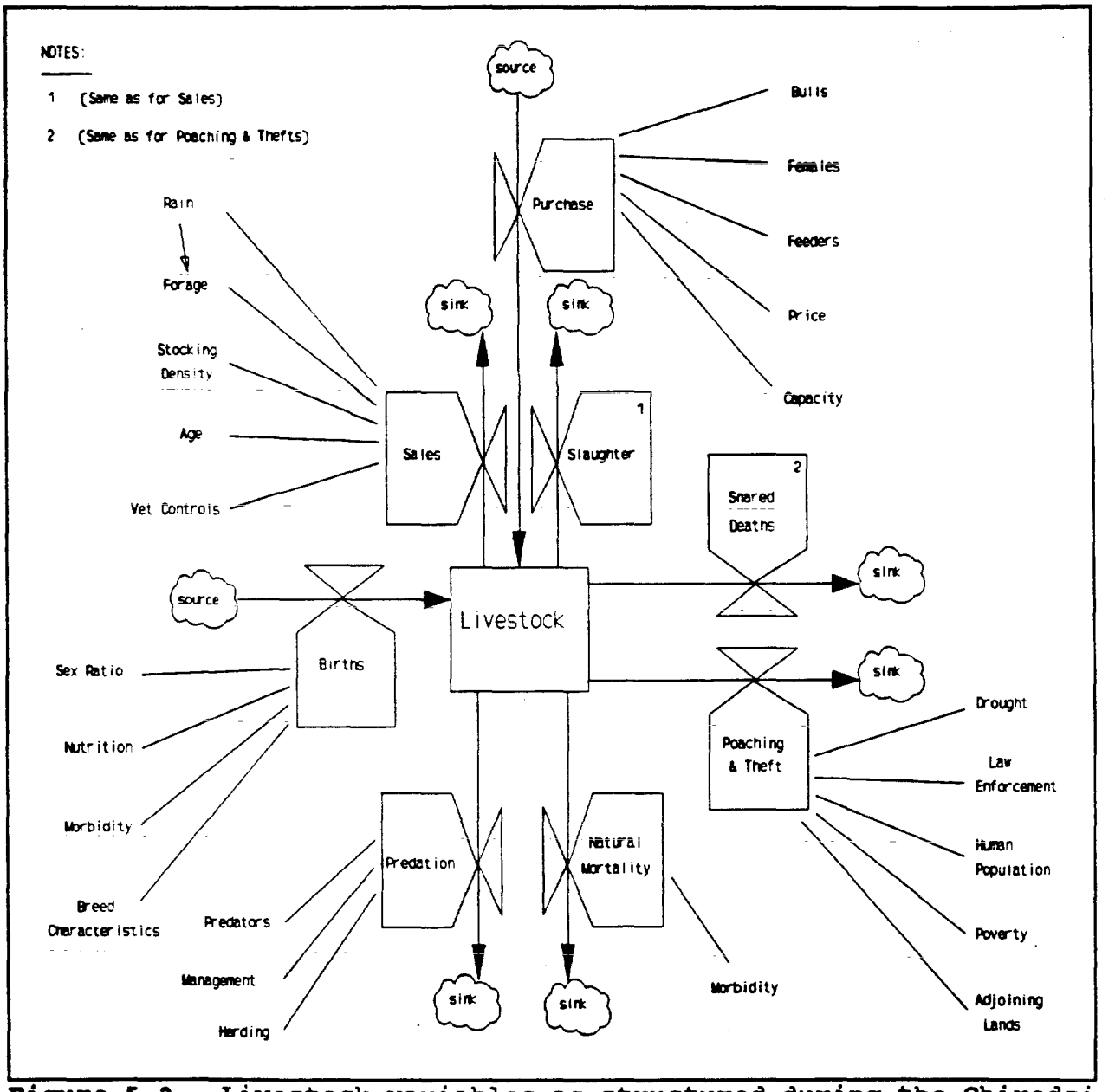


Figure 5-3. Livestock variables as structured during the Chiredzi workshop.

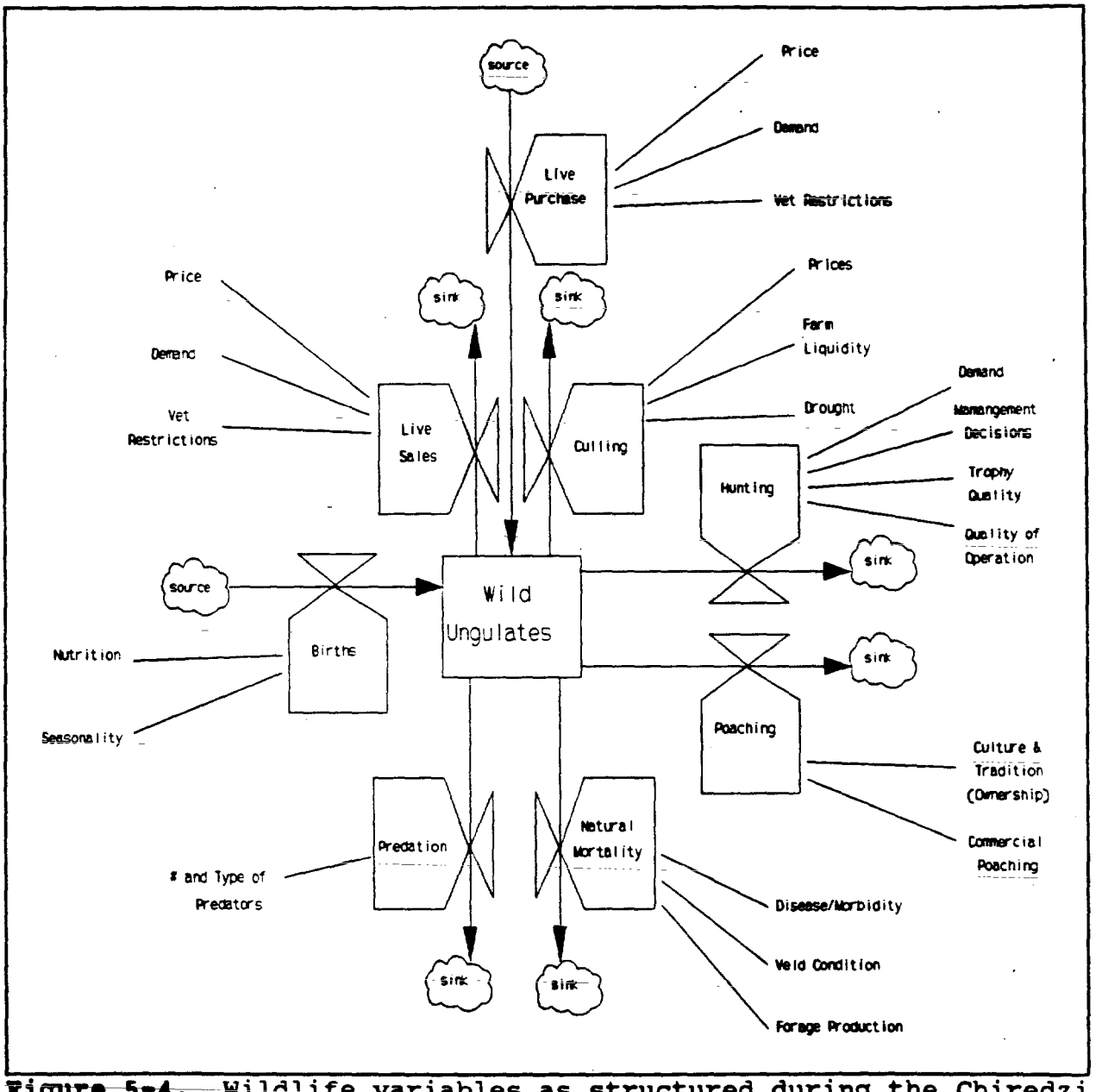


Figure 5-4. Wildlife variables as structured during the Chiredzi workshop.

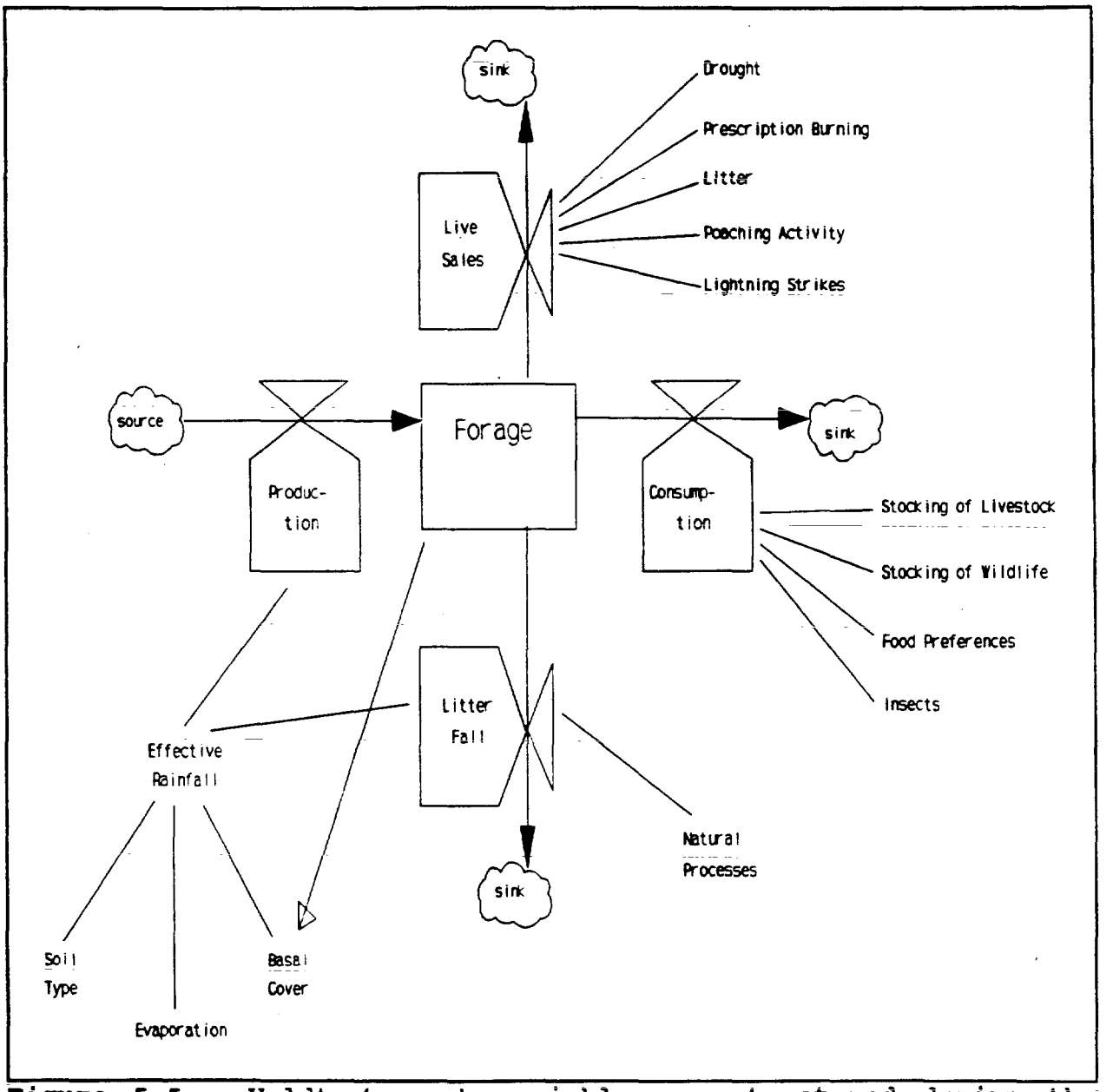


Figure 5-5. Veldt (range) variables as structured during the Chiredzi workshop.

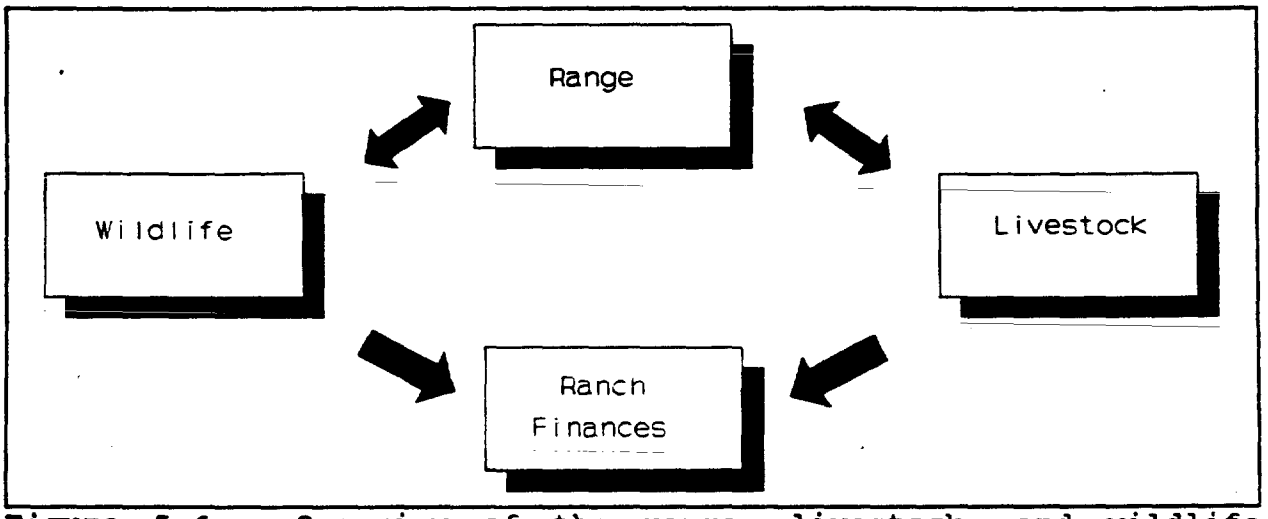


Figure 5-6. Overview of the range, livestock, and wildlife submodels.

5.3 Schematic Model of a Range, Livestock, and Wildlife System

5.3.1 Overview

The Range, Livestock and Wildlife model was developed based on the results of the workshops described in the previous section. In order to validate the model as reported in Chapter 6, it was assembled from three primary submodels (range, livestock, and wildlife), and an accounting component (See Figure 5-6).

5.3.2 Range Submodel

The most basic resource upon which the entire system depends is the range. The range subsystem provides the primary production, forage, to support the secondary production, livestock and wildlife. The health and productivity of the range resource is undoubtedly the most critical element in the welfare of the entire system.

There are no direct interactions between livestock and wildlife except for predation and disease (See Figure 5-6). However, by competing to use the range resource there can be considerable indirect interaction between the two groups. The limits of forage production impose a corresponding limit on the animal productivity and biomass that can be supported by the range. To the extent that livestock utilize the range, wildlife

must be excluded or overuse will reduce range productivity. This is particularly true of those wild ungulates which prefer the same grasses grazed by livestock, especially cattle. Animals which prefer shrubs and trees (browsers) may not compete directly with livestock, although most animals may change their consumption habits at certain times for a variety of reasons.

Plant Biomass. The key stock and indicator of the range resource subsystem is plant biomass. Plant biomass is modeled as an average of the entire range for the sake of simplicity and ease of understanding (See Figure 5-7). This "average" or "typical" hectare aggregates all the different characteristics such as soil types, landscapes, and rainfall regimes. Any aggregation generates a certain degree of inaccuracy, but without abstractions and simplifications the modeling process would be either prohibitively expensive or impossible. This simplification is a reasonable one for our purposes as defined in the previous sections.

Four plant types are modeled independently using the same structure as in Figure 5-7. These four types represent the major categories of plants present in most range systems:

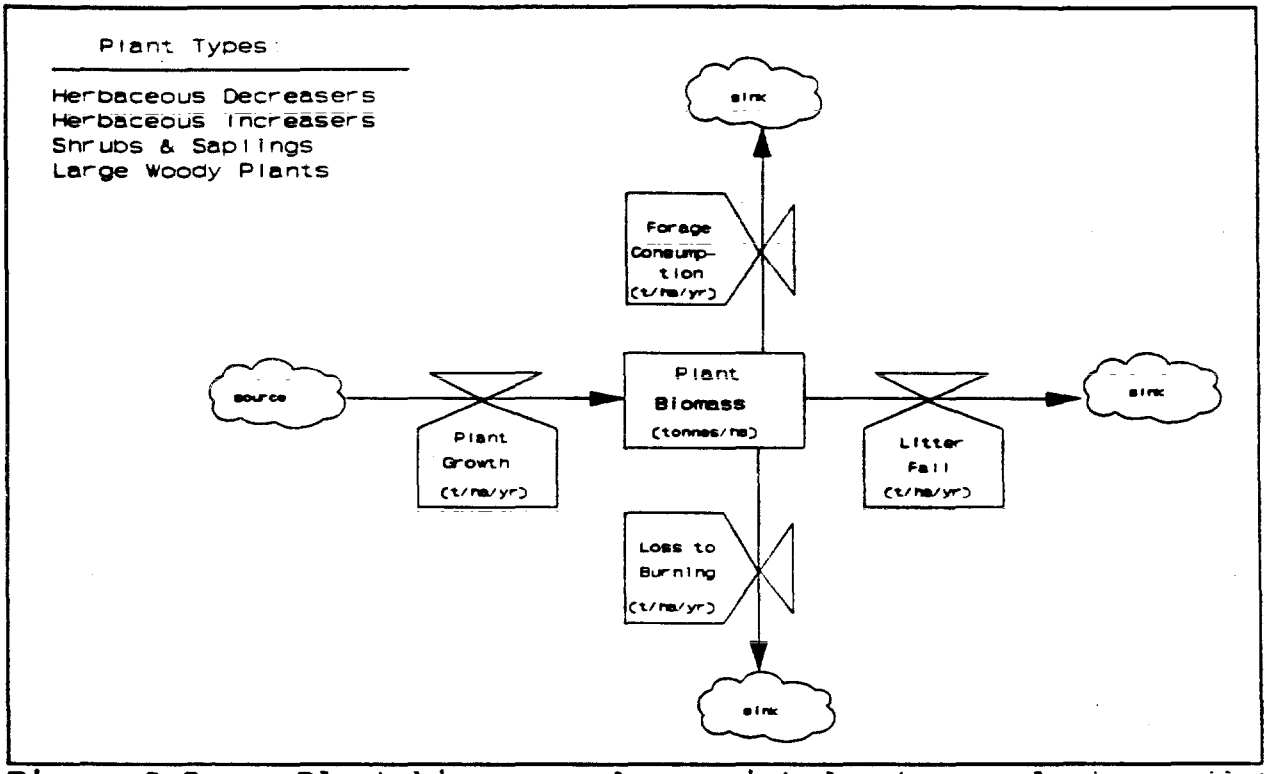


Figure 5-7. Plant biomass and associated rates: plant growth, forage consumption, litter fall, and loss to burning.

Herbaceous Decreasers are preferred by most grazing animals and tend to predominate in undisturbed systems, but become less abundant under grazing pressure, thus the term "decreaser". In most cases, herbaceous decreasers are perennials which are more palatable and have a higher protein content. The ratio of decreasers to total grass biomass is an indicator of range condition.

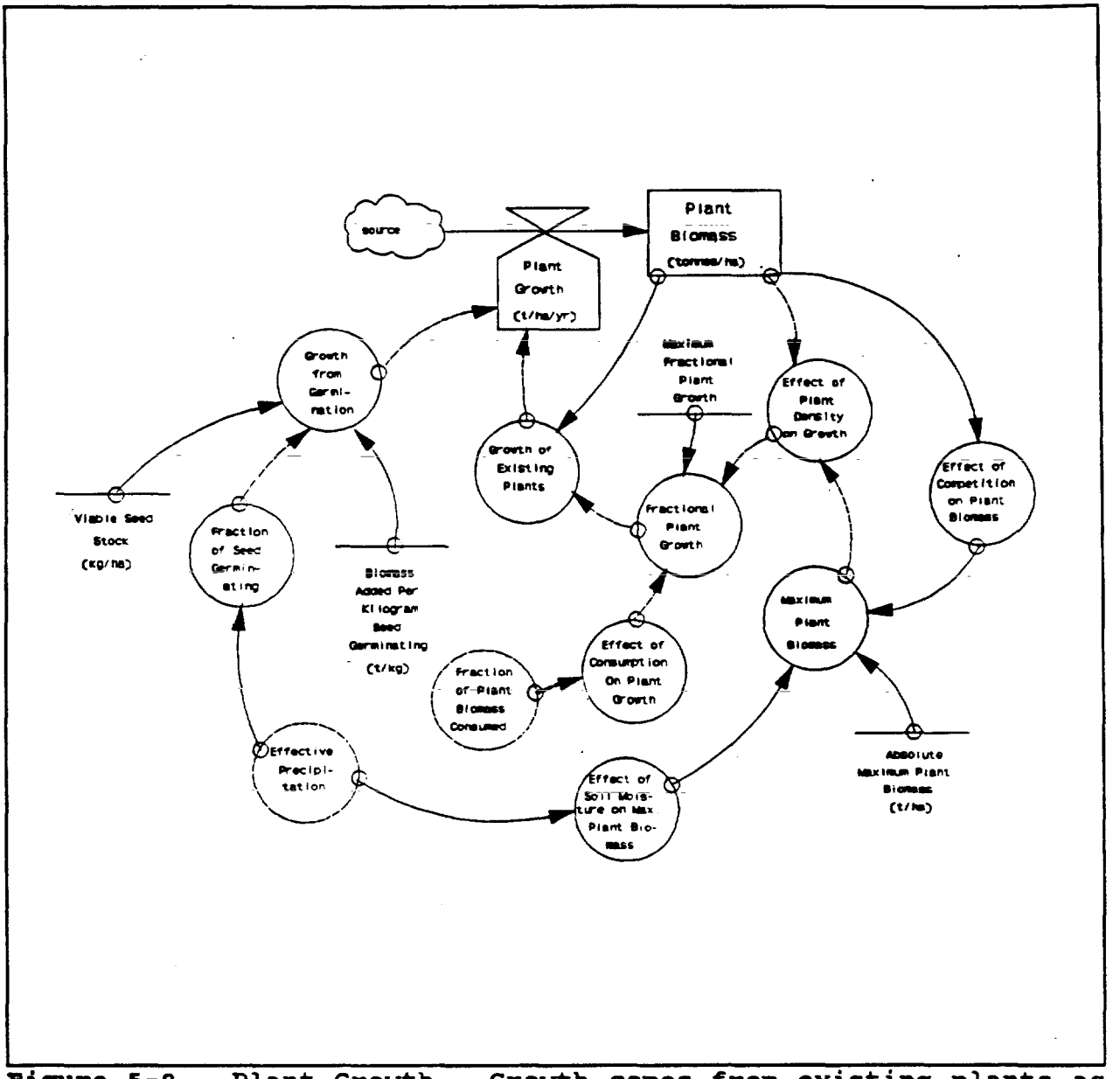


Figure 5-8. Plant Growth. Growth comes from existing plants as well as seed. Precipitation and competition limit growth.

Herbaceous Increasers tend to be annual grasses and less palatable. Under proper range use, increasers make up about 10% of the grass plants. However, when the range is overgrazed increasers become more prevalent because their lower palatability

and other conditions tend to give them advantages over the decreasers.

Shrubs and Saplings are larger perennial plants and small trees.

Large Woody Plants are trees, and in Africa are commonly known as "bush."

Four flows or rates determine the amount of plant biomass on the range: plant growth, forage consumption, litter fall, and loss to burning.

Plant Growth. Plant growth is the only rate which increases the level of plant biomass (See Figure 5-8). In range science, growth is often referred to as productivity. Two sources of plant growth are existing plants and seed. Seed germination is dependent upon the effective precipitation -- the precipitation that infiltrates into the ground (See Figure 5-9). The amount of viable seed stock, here shown as a constant, provides the seed for germination. For each kilogram of germinating seed, a given amount of biomass is added to the plant stock.

Growth from existing plants is represented in a considerably more complex manner. As would be expected, growth from existing plants is first determined by the amount of plant biomass already present. Additionally, plant productivity is important, and is represented by the fractional plant growth. The plant growth fraction is the capacity plants have for increasing the existing stock over the course of a year. The maximum fractional plant

growth of grasses is close to one, meaning that about 100 percent more plant biomass can be added in a year.

However, this maximum can be constrained for several reasons, including consumption. A certain amount of the plant can be eaten and the plant will maintain its productivity; this amount is termed proper use. If too much of the plant is consumed, the plants experience stress and productivity declines (See Figure 5-10). This loss of productivity varies with plant type; decreasers are hit particularly hard.

Plant density can also limit plant growth. When biomass approaches the maximum as limited by soil moisture and competition from the other plant types, growth slows. An absolute maximum of plant biomass reflects factors such as soil, precipitation, and temperature, and puts an upper limit on the stock of plant biomass for each type.

Effective Precipitation. Precipitation is explicitly modeled because it is such an important and limiting factor in the productivity of African rangelands (See Figure 5-9). All soils have certain characteristics which allow them to accept and hold limited amounts of moisture. These characteristics vary in different soils. The model mimics this infiltration and retention capacity for effective precipitation by defining a maximum effective precipitation and choosing between the lesser of the maximum defined and the total annual precipitation.

Precipitation is randomly generated using the mean and standard deviation from historical data.

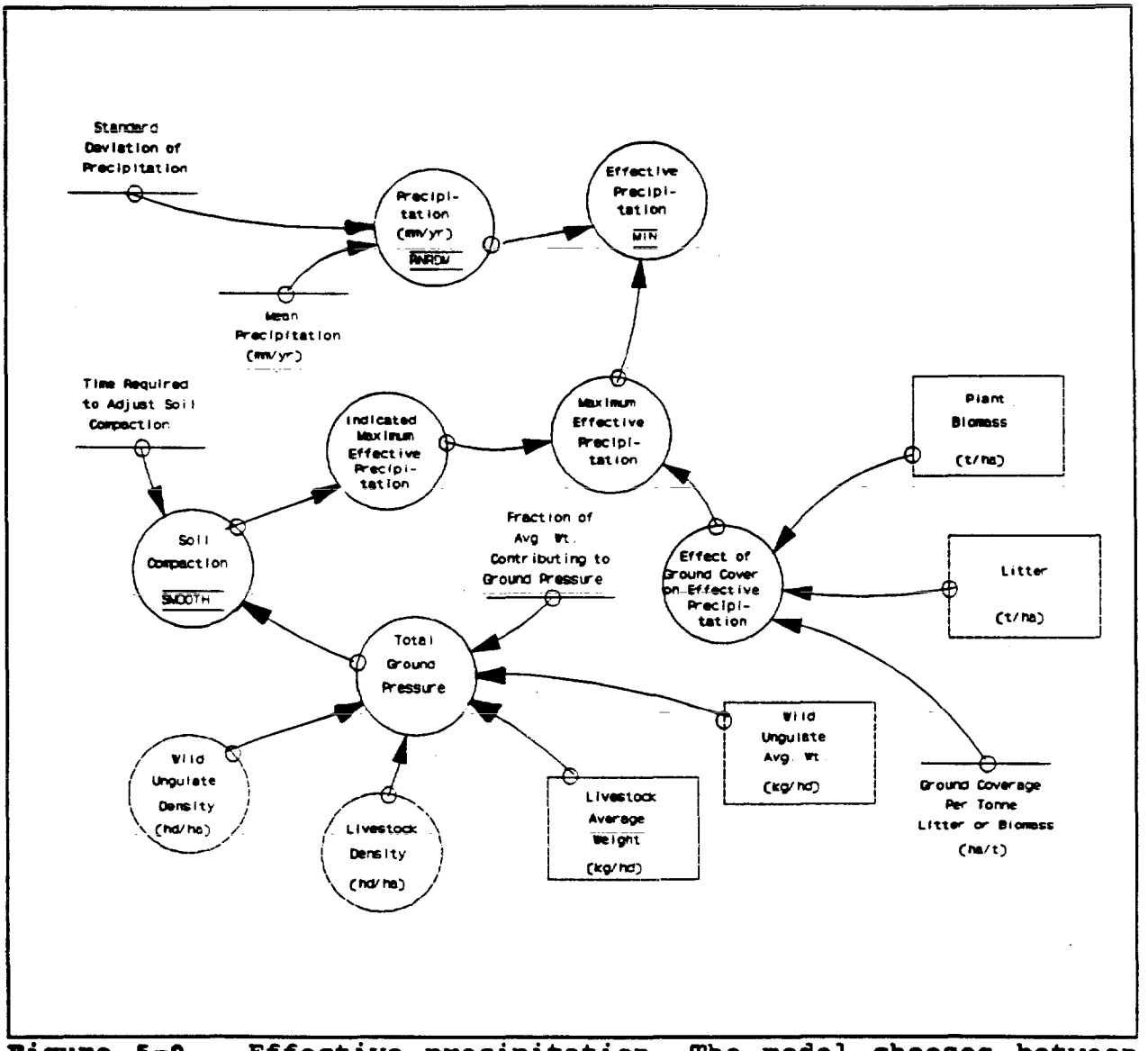


Figure 5-9. Effective precipitation. The model chooses between numbers generated randomly using historical data or a maximum as determined by soil cover and compaction.

Maximum effective precipitation is determined by two primary effects: soil compaction and soil cover. Soil compaction is a function of total ground pressure from wild and domestic ungulates. Larger animals contribute more to ground pressure per unit of weight than do small animals, so the herd composition is as important as the stocking density and average weight. The effect of size on ground pressure is represented by the fraction of weight contributing to ground pressure, which has a different value to reflect each animal category for wild ungulates and livestock. This fraction is low for small animals and one or approaching one for large animals.

Ground cover is important to reduce the impact of rainfall and improving water infiltration into the soil. The total ground cover is a fraction; one would indicate 100 percent coverage. Plant biomass and litter contribute in varying degrees to soil cover. The value of ground cover per tonne litter or biomass is different for grasses, shrubs, trees, and litter.

Forage Consumption. Humans have the capacity to manage this critical element of range use for better or for worse. In the strict sense, we do not manage stocks, but only the rates which determine them. In the range system it is really only possible for a manager to directly alter forage consumption by means of stocking density and herd composition for both domestic and wild animals. Burning or fighting range fires are also tools for altering the range.

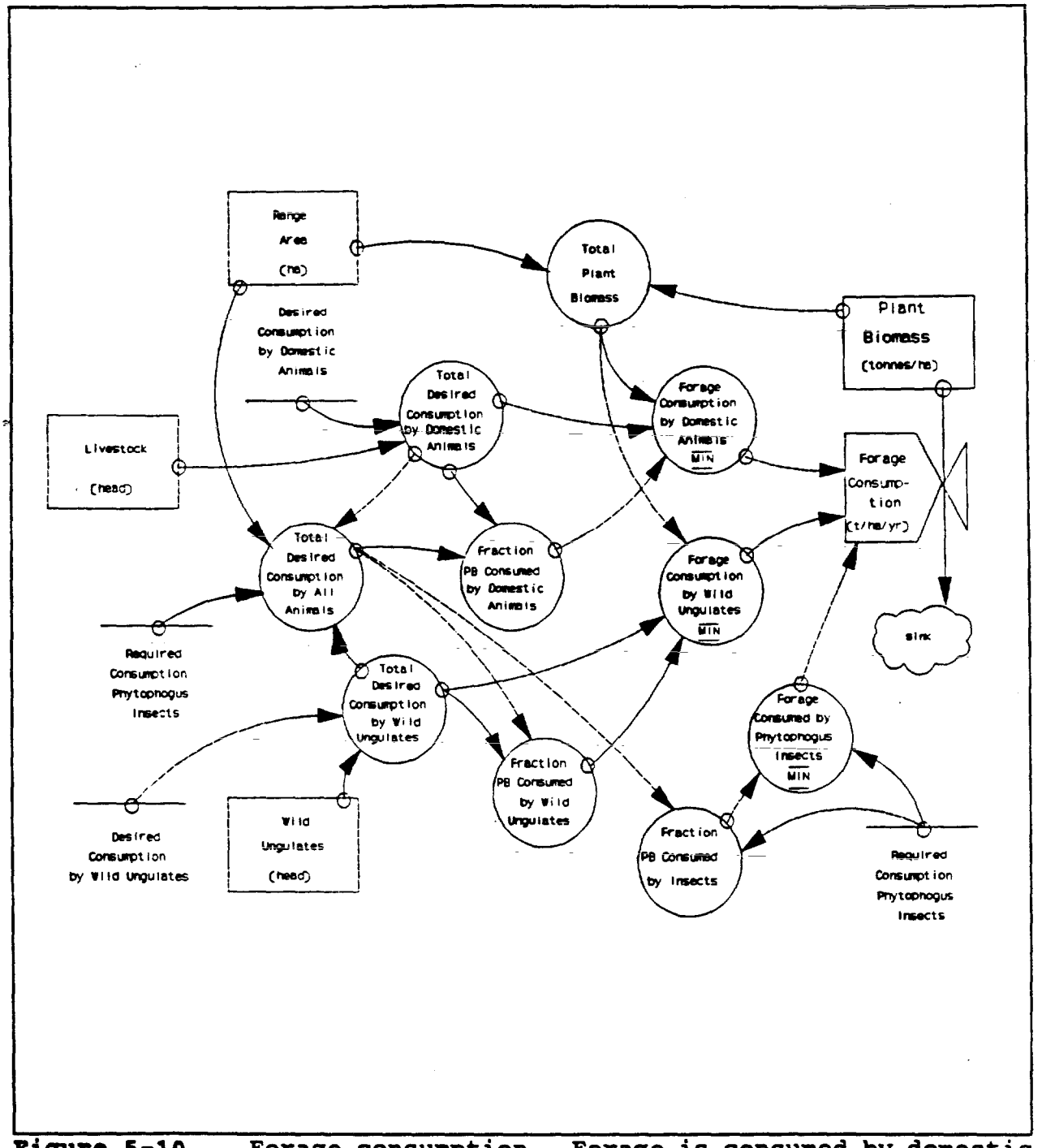


Figure 5-10. Forage consumption. Forage is consumed by domestic animals, wild ungulates, and insects. The amount consumed is determined by availability and requirements.

The total forage consumed is the sum of consumption by domestic animals, wild ungulates, and insects. Each of these remove a share of the plant biomass depending upon their density and requirements (See Figure 5-10). The consumption by each category is the actual requirement, or if plant biomass is limiting, the fraction of total consumption each category wants multiplied by the amount of plant biomass. In this way, consumption cannot exceed availability. If desired consumption is greater than the stock of plant biomass, then the allowed consumption is allocated according to the fraction of the total desired consumption that each category of consumer requires or desires. Thus, if insects require 100 kilograms per hectare and the other categories require a total of 400 kilograms per hectare, but only 300 kilograms per hectare is available, then the insects will receive 20 percent (100/500) of the plant stock, or 60 (0.2 x 300) kilograms per hectare. The other categories would receive the remaining 80 percent.

Litter Fall. All plants experience some degree of drying and loss of leaves and other plant structures. The accumulation of this material on the ground is called litter. To mimic this in the model, the plant biomass of each type is multiplied by a fractional litter fall. This multiplier is determined by a normal litter fall fraction which is characteristic of each plant category, and by the fraction of plant biomass consumed. For some plants such as perennials, the fraction of litter falling is

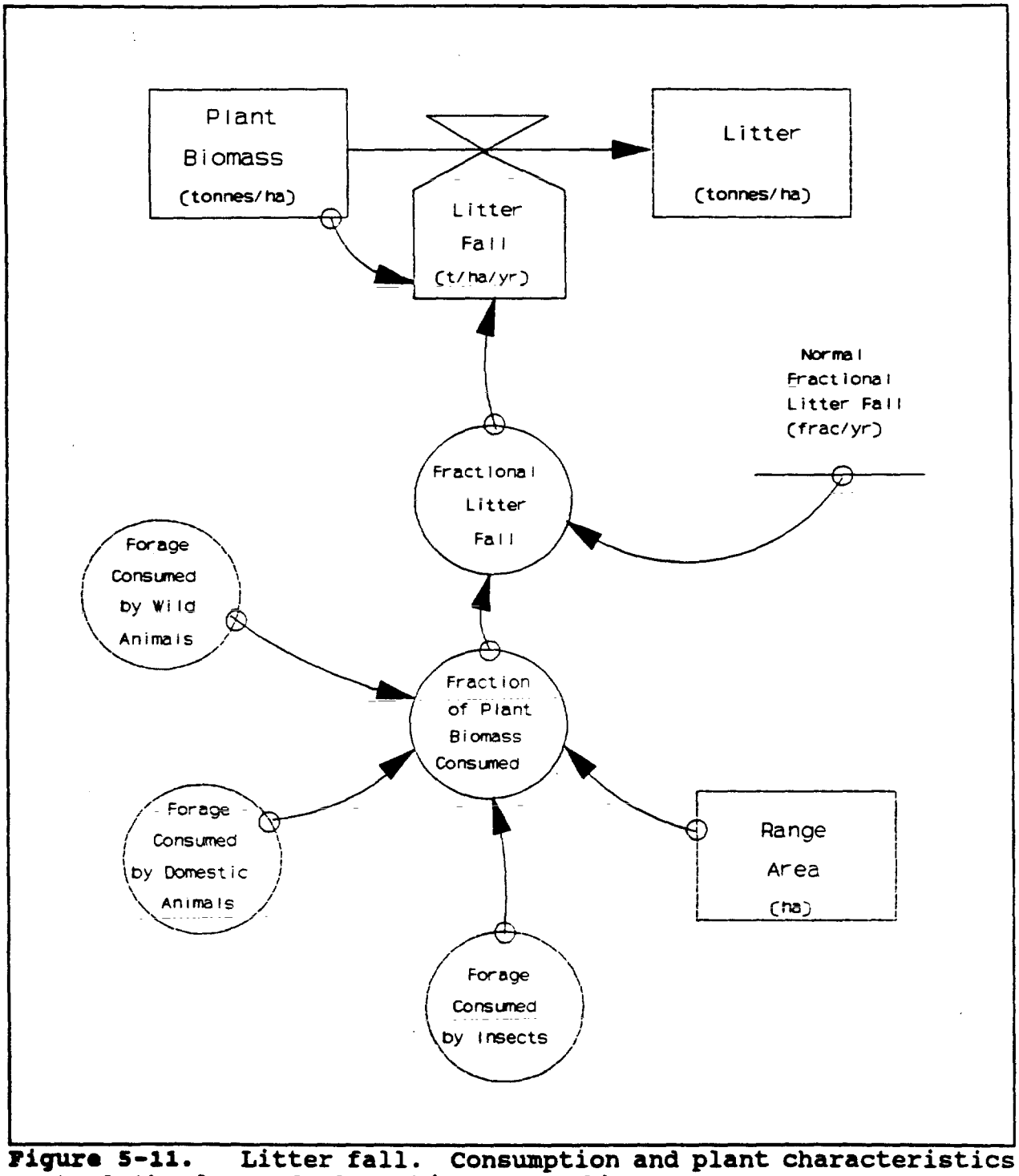


Figure 5-11. Litter fall. Consumption and plant characteristics control the loss of plant biomass to litter.

reduced because the material that would have fallen was instead eaten. For other plants, such as annuals, all of the material

falls to litter no matter how much is consumed (See Figure 5-11).

Loss to Burning. In Africa, range fires are a fairly common. These fires can be started by lightning strikes or set purposely as a range management tool, for example to control bush. Fires are also set by poachers and herdsmen in an attempt to attract herbivores to the flush of grass that results after the burn. In many areas, and in particular on most commercial ranches, fires are actively suppressed to the extent possible. There is the legitimate fear that if the fire gets out of control all forage will be lost, temporarily leaving animals with nothing to eat.

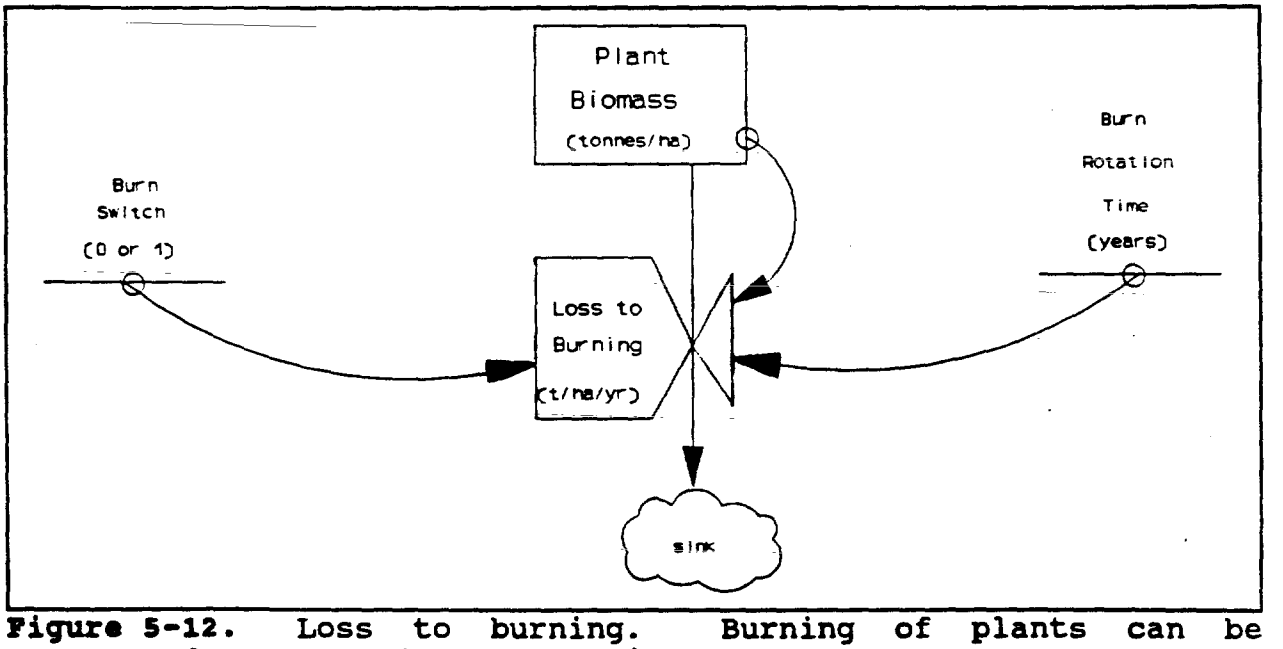


Figure 5-12. Loss to burning. Burning of plants can be suppressed or managed on a rotation.

Burning can be modeled on a rotational basis or completely suppressed (See Figure 5-12). If burning is allowed, the burn

switch will be set to one; if fire is suppressed the switch is zero. This assumes that suppression can be successful. Given the normal accuracy of these models, this is a reasonable assumption because losses of less than 1 percent or so become insignificant.

A normal burn rotation would on the order of twenty years. This means that 5 percent of the biomass in each plant category is lost to burning. In actuality of course, 5 percent of the range area would be completely burned. However, because the range area is aggregated into a typical or average hectare, we remove this loss from the average.

Release of Shrubs and Saplings. Large woody plants (trees), cannot sprout directly from seed. There is always a time period for the young seedlings and saplings to mature. At a certain point in their growth, they are "released" and can then be categorized as trees. A primary determinant of this release rate is the form of the plant. Plants that have been heavily grazed assume a hedge-like shape, which prevents their release because new growth is always within reach of browsing animals.

Litter. Plant litter is an important determinant of effective precipitation (See Figure 5-10). Litter is increased by litter fall (See Figure 5-11), lost to burning (See Figure 5-12) and decay (See Figure 5-14). Decay times are relatively short in the tropics, about one year until the litter is broken down into humus.

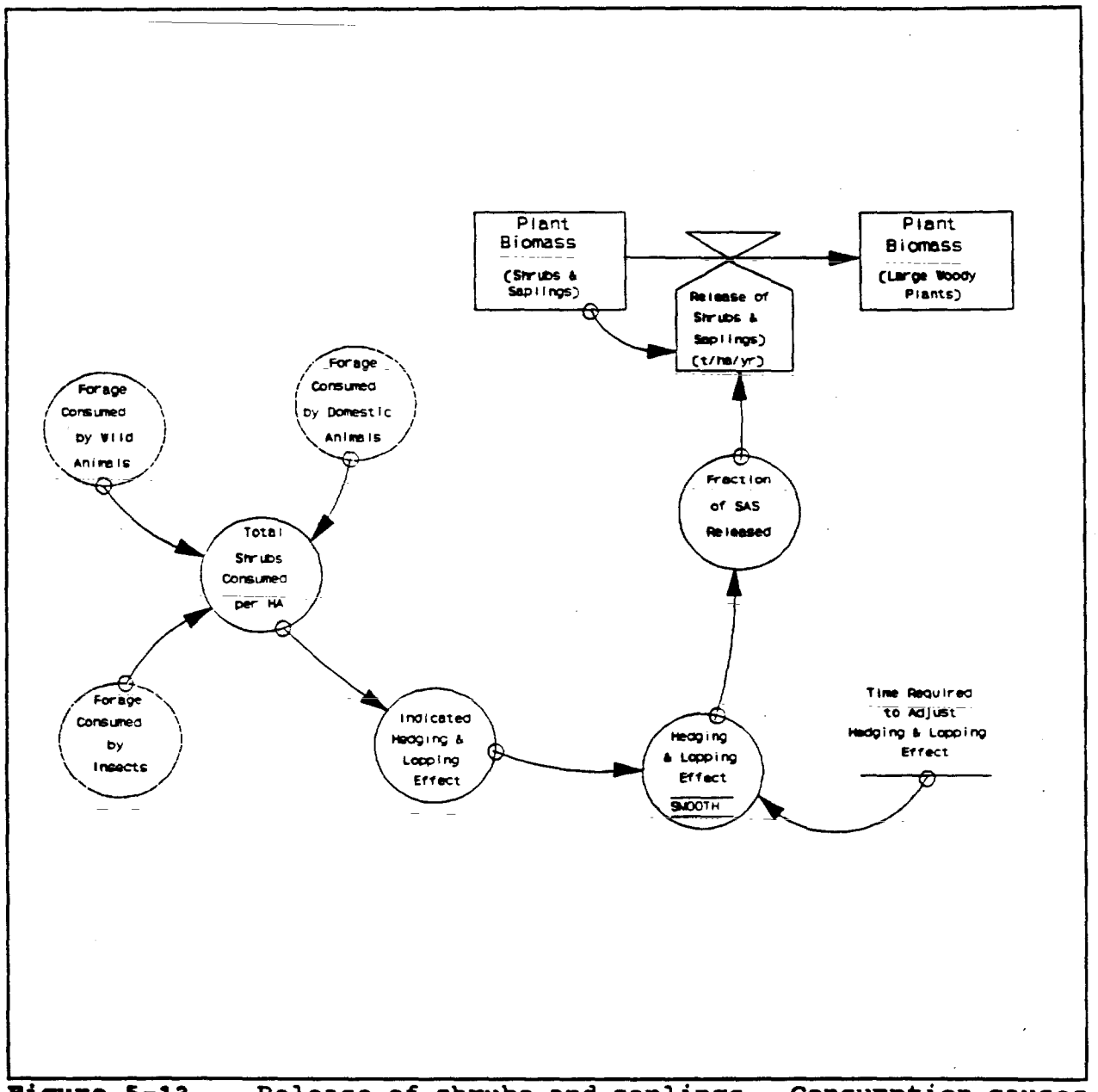


Figure 5-13. Release of shrubs and saplings. Consumption causes shrubs and saplings to take on a hedge-like form, inhibiting release.

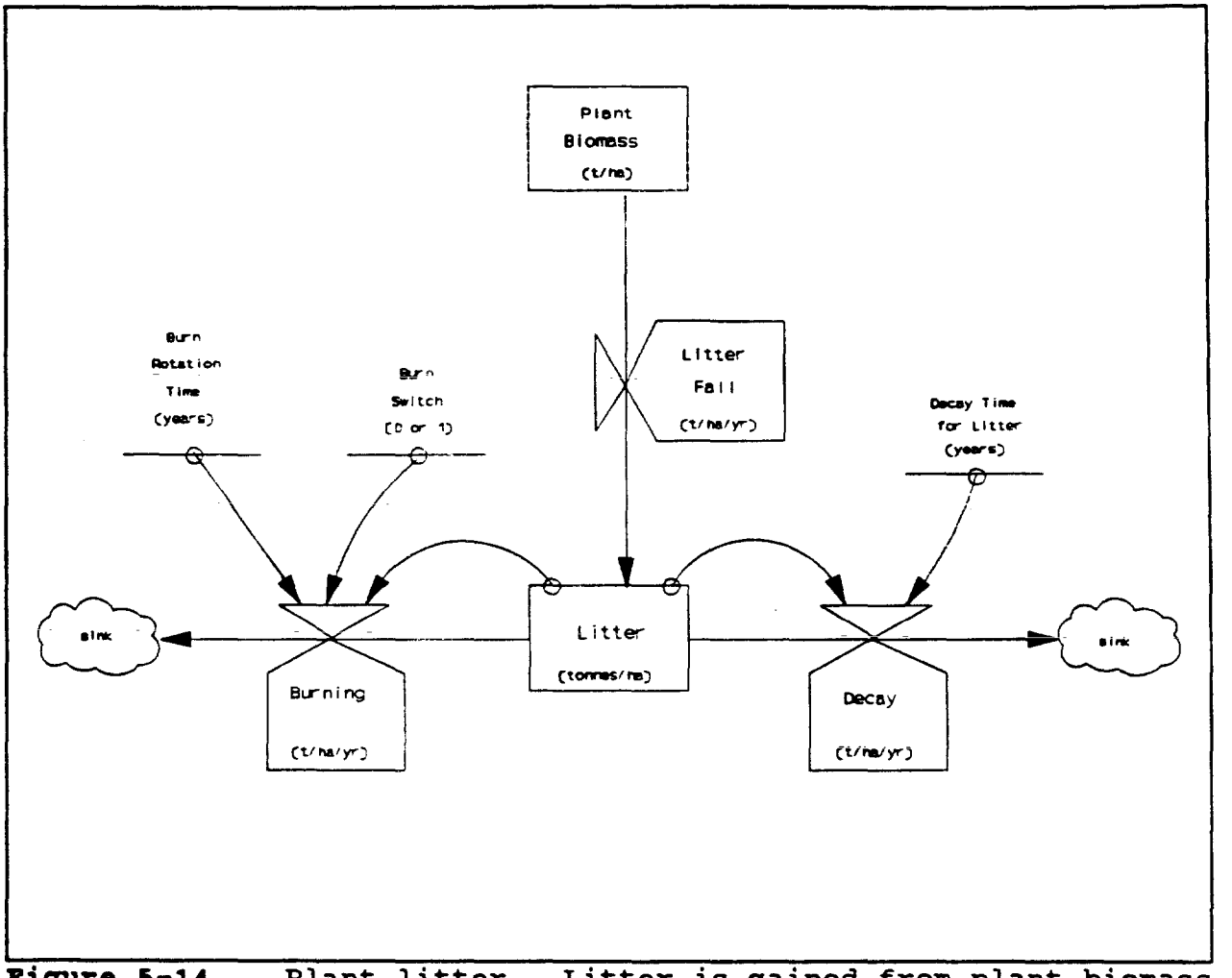


Figure 5-14. Plant litter. Litter is gained from plant biomass losses, and lost to burning and decay.

5.3.3 Livestock Submodel

Three categories of livestock are represented in the model: immature cattle, mature male cattle, and mature female cattle (See Figure 5-15). Other livestock are not significant on Buffalo Range, and are not represented.

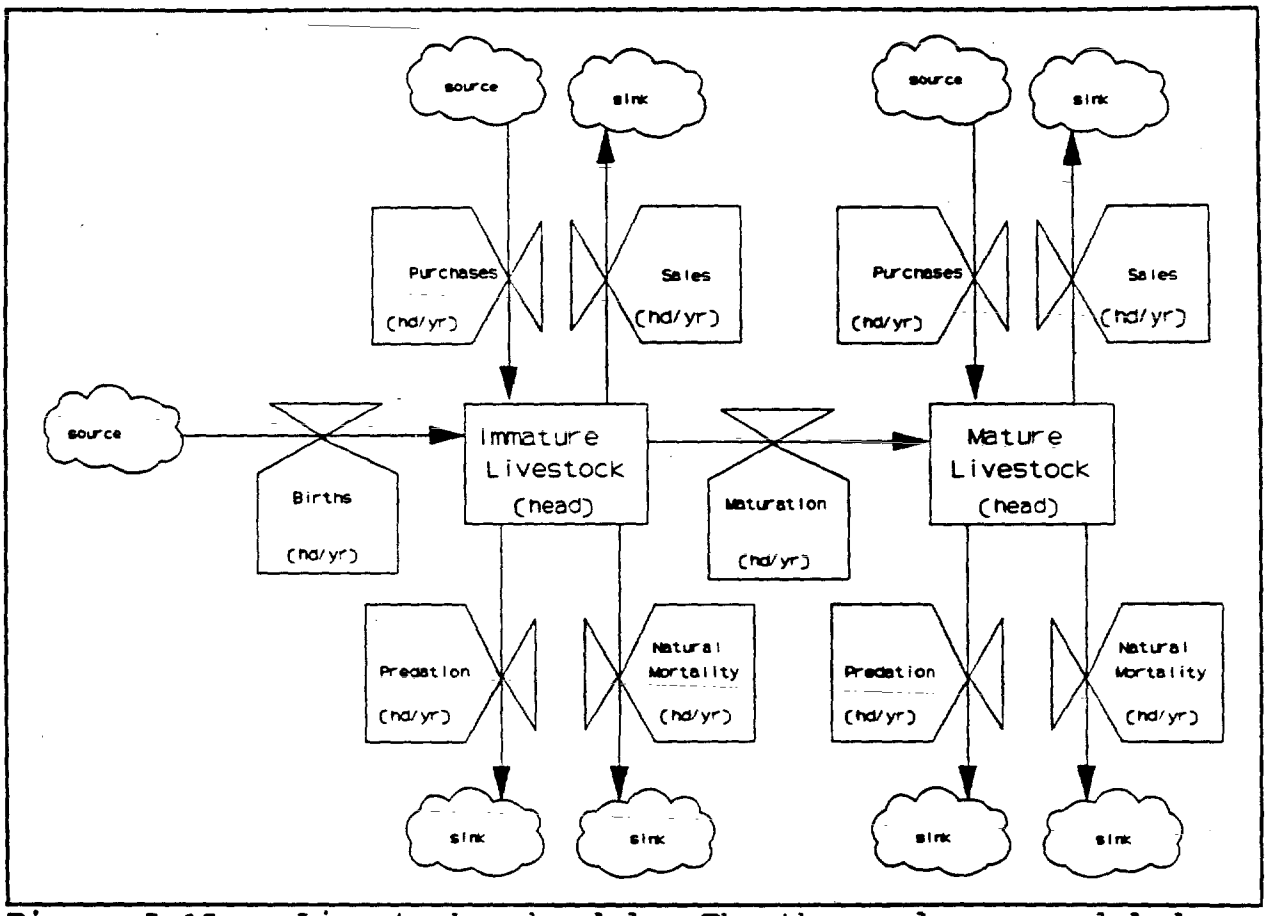


Figure 5-15. Livestock submodel. The three classes modeled are immature cattle, mature male cattle, and mature female cattle (mature classes are together in this drawing).

For immature livestock, numbers can increase from births and purchases, and decrease from sales, maturation, natural mortality, and predation. The sources for mature livestock are

maturation and purchases, and the sinks are sales, natural mortality, and predation.

Livestock Births. Births are a function of several factors, the breeding herd size, breed characteristics, nutrition, and morbidity. The model captures these factors by multiplying the stock of mature females by a birth fraction which aggregates the effects breed, nutrition, and morbidity (See Figure 5-16).

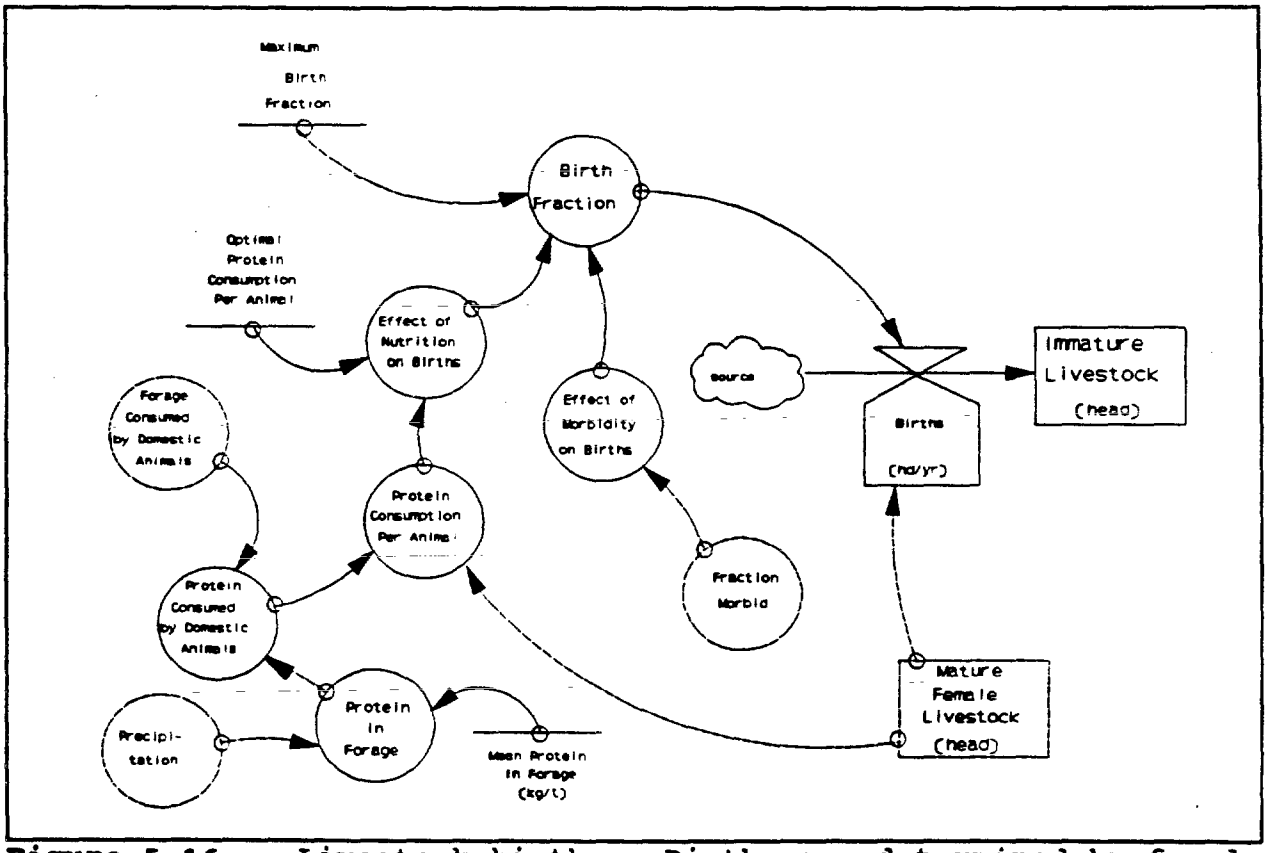


Figure 5-16. Livestock births. Births are determined by female stock, breed characteristics, nutrition, and morbidity.

Each type and breed of livestock exhibits a maximum potential birth fraction, which is constrained by the effects of nutrition and morbidity. Only when the herd is healthy and well

fed can the maximum be achieved. These effects are also characteristic of the type and breed of animal. For example, births tend to drop off faster in smaller animals when nutrition declines.

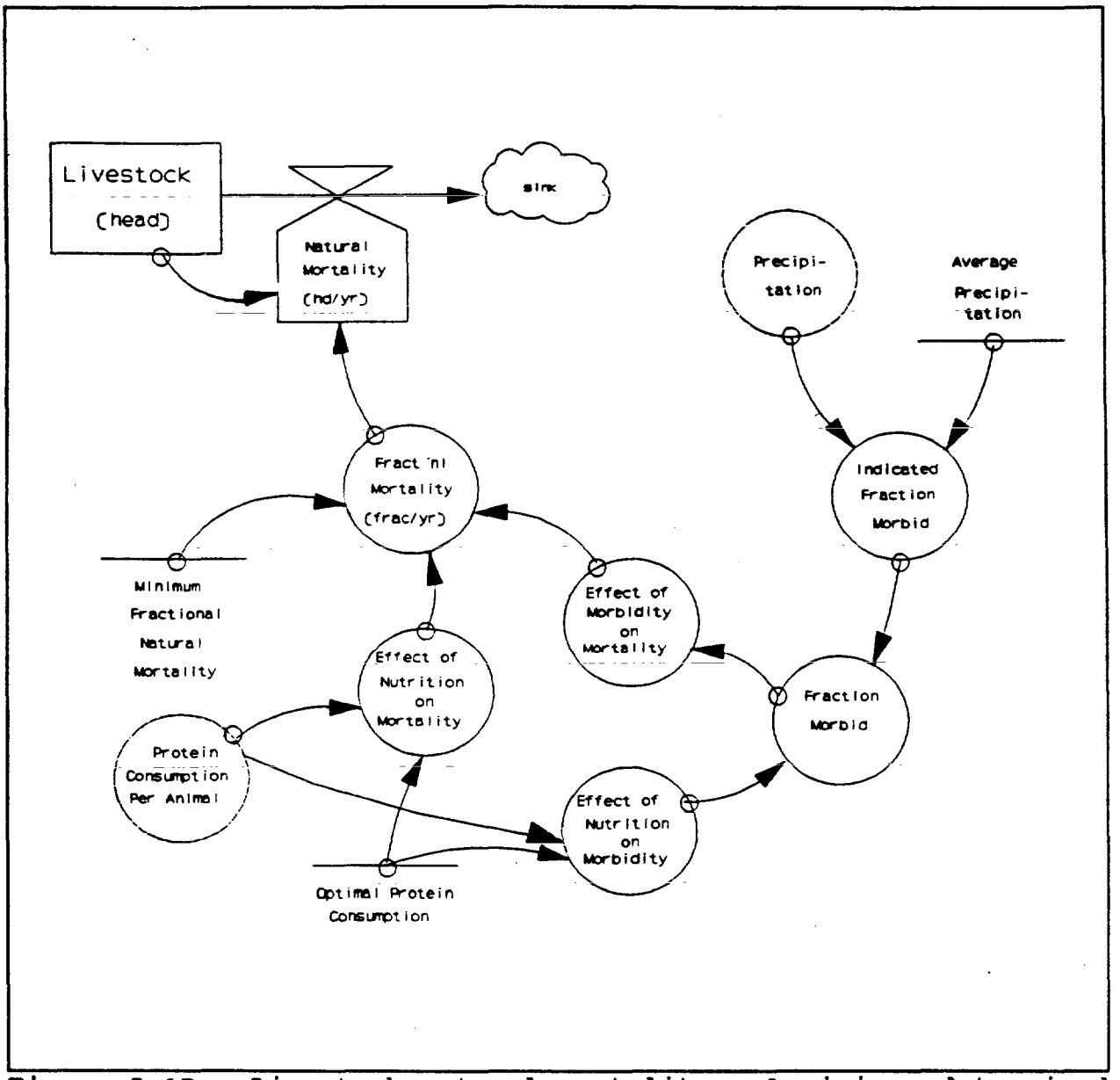


Figure 5-17. Livestock natural mortality. A minimum determined by breed, age, and sex can be increased if nutrition is poor and morbidity high.

Protein consumption, an important nutritional component, can be used as an indicator for nutrition. Protein is derived from the forage consumption, and as such is subject to forage quality and availability. Under proper stocking and good range

conditions forage availability and quality is usually not a problem, but drought periods always reduce availability and quality. Additionally, overgrazing can shift the species balance to grasses of lower protein content, which reduces protein consumption even when forage is available in sufficient quantities.

Livestock Natural Mortality. Most of the same factors that determine livestock births also contribute to natural mortality (See Figure 5-17). The exception is that mortality acts on all livestock classes, but births are a function of only female stock. Each class of stock has its own natural mortality rate as determined by breed, age, and sex, as well as nutrition and morbidity. Each livestock class has a minimum rate of natural mortality which can be increased by nutritional deficiencies and morbidity. Morbidity in this model is influenced by precipitation as well as nutrition because periods of extreme dryness or wetness increase disease effects.

Livestock Maturation. After a period of time, if immature animals are not sold or die, they become sexually mature. It is important to distinguish the larger and reproductively capable animals from the smaller immature animals because they have a greater effect on the range and herd size (See Figure 5-18).

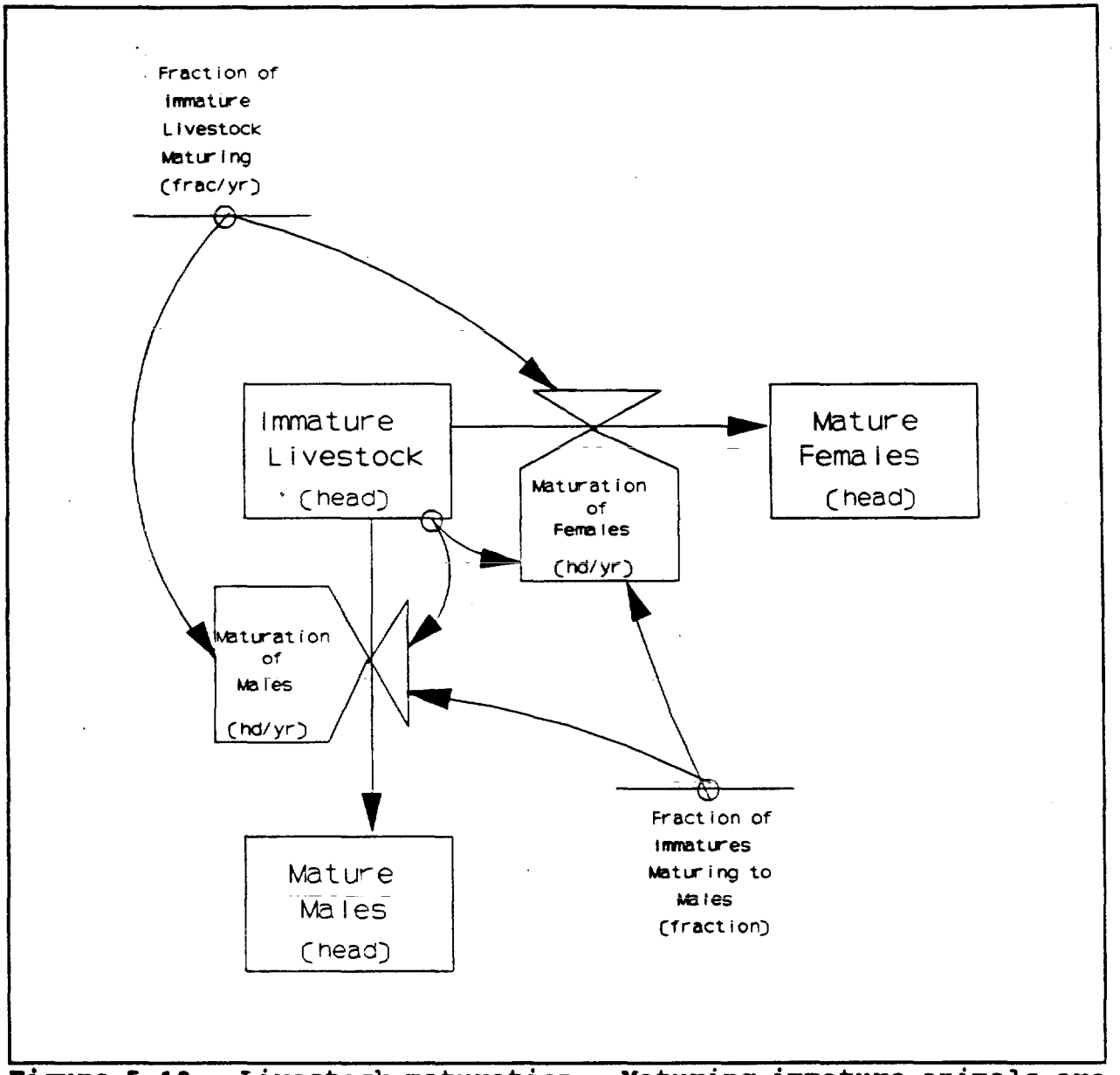


Figure 5-18. Livestock maturation. Maturing immature animals are split into males and females.

Livestock Sales and Purchases. The sale and purchase of livestock are the primary mechanisms through which the ranch manager controls herd size, and therefore stocking densities. In addition, animals are bought and sold to maintain herd

productivity, liquidity of the ranch, and purely for speculation. Depending on the type of operation (for example in feeder operations), significant fractions of the herd may be sold concurrent with large purchases of new animals.

In calculating the number of animals of each class to be bought or sold, the ranch manager must first set the desired herd size for each class. Livestock may be bought or sold at all times, but usually sales increase when the herd is too large, while purchases increase when the herd is too small. The desired herd size acts as a "goal" for herd size and proper range stocking.

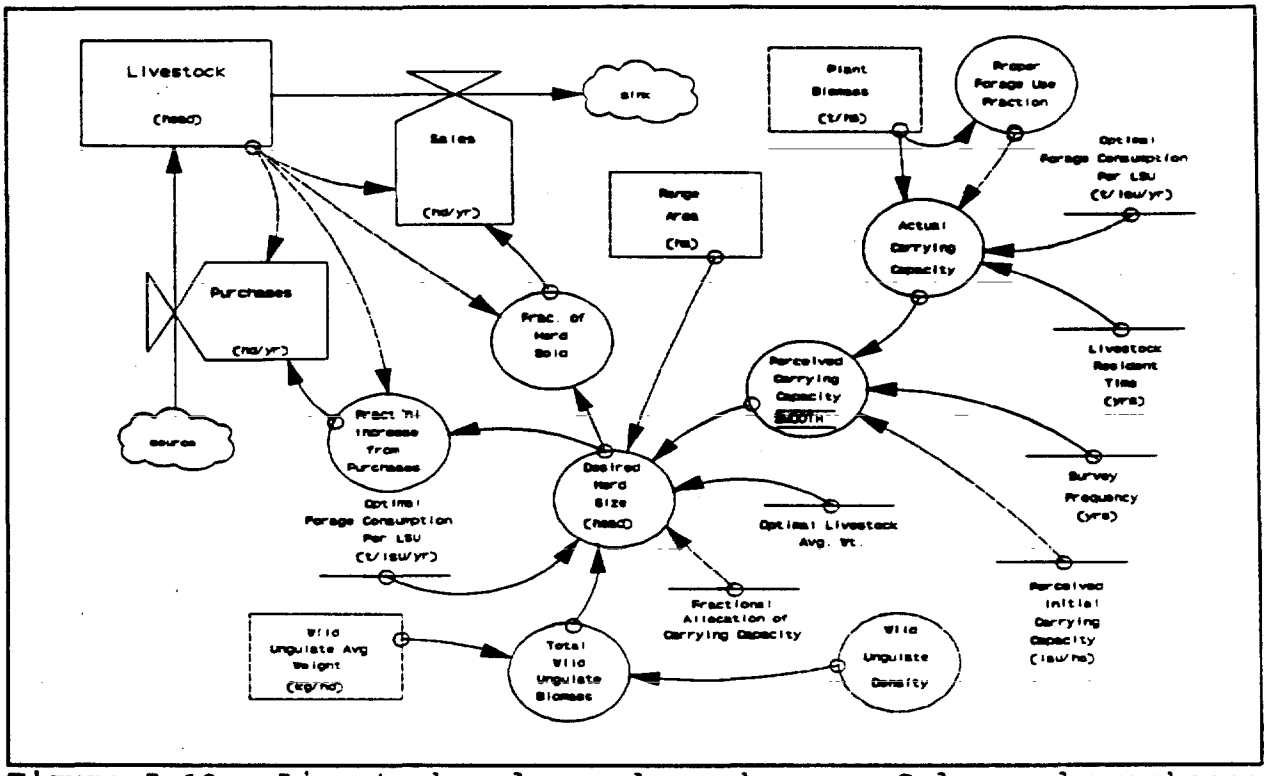


Figure 5-19. Livestock sales and purchases. Sales and purchases are determined by desired herd size, which is a function of perceived carrying capacity. This perception can be constant or related to actual capacity.

Desired herd size can be relatively simple or difficult determination, depending on the method employed by the rancher. In the simplest case, the rancher may use a rule-of-thumb (in Zimbabwe this is referred to as a "thumbsuck"), to set herd size. Often this number is set by the local extension agent and gives the rancher an approximation of the proper stocking density for the region. If this is the case, the model sets the <u>perceived carrying capacity</u>, (as perceived by the rancher) at the initial value (See Figure 5-19). This perceived capacity, in livestock units (LSU) per hectare, is then multiplied by the range area and

allocated across the classes according to livestock weight and type of operation.

For example, if the stocking density is one LSU in ten hectares, and the ranch size is 10,000 hectares, then the range can support 1,000 livestock units. A livestock unit is defined as a cow and calf, or 455 kilograms of liveweight. The total livestock biomass would then be 455,000 kilograms. If the allocation of this biomass is set at 25 percent immature, 25 percent mature male, and 50 percent mature female stock, then the allocations of biomass to those classes would be 113,750, 113,750, and 227,500 kilograms, respectively. These weights must then be divided by the optimal weight per animal for the class: 136 kilograms for immature, 550 kilograms for mature males, and 386 kilograms for mature females. Thus, the desired herd size would be 836 immature cattle, 206 mature males, and 589 mature females.

Other factors can be considered which make the determination of desired herd size more complicated, but also more accurate. The rancher may consider the biomass of wild grazers to reflect their consumption and competition for the available forage. This source of competition may be considerable in many instances, and is usually difficult or impossible to eliminate. In the model, this can be accomplished by setting the <u>wildlife accounting switch</u> (not shown) from zero to one.

Additionally, the rancher may decide to set the desired herd size according to actual forage availability and range condition. This involves the use of annual or semi-annual surveys and a determination of proper use, that is, the plant biomass fraction that can be removed under a given range condition. For range in good condition, proper use is about 50 percent, and under extreme degradation, may be zero. The model continuously estimates proper use and actual carrying capacity, but these only become part of the perceived carrying capacity if the survey switch is set to one. In the base case reported in Chapter 6, both the wildlife accounting and survey methods are not used, as is the custom in the low veld of Zimbabwe.

Predation of Livestock. Two factors are important in predation, which may significantly reduce the herd. First, the number and type of predators -- just as herbivores have preferences for and abilities to consume certain plants, so do predators have preferences for and abilities to prey upon classes of animals. Second, the animal density determines the availability of the prey and the number of kills per predator. Kills per predator reflects the predator preference, prey density, as well as herding, although this is not explicitly modeled (See Figure 5-20).

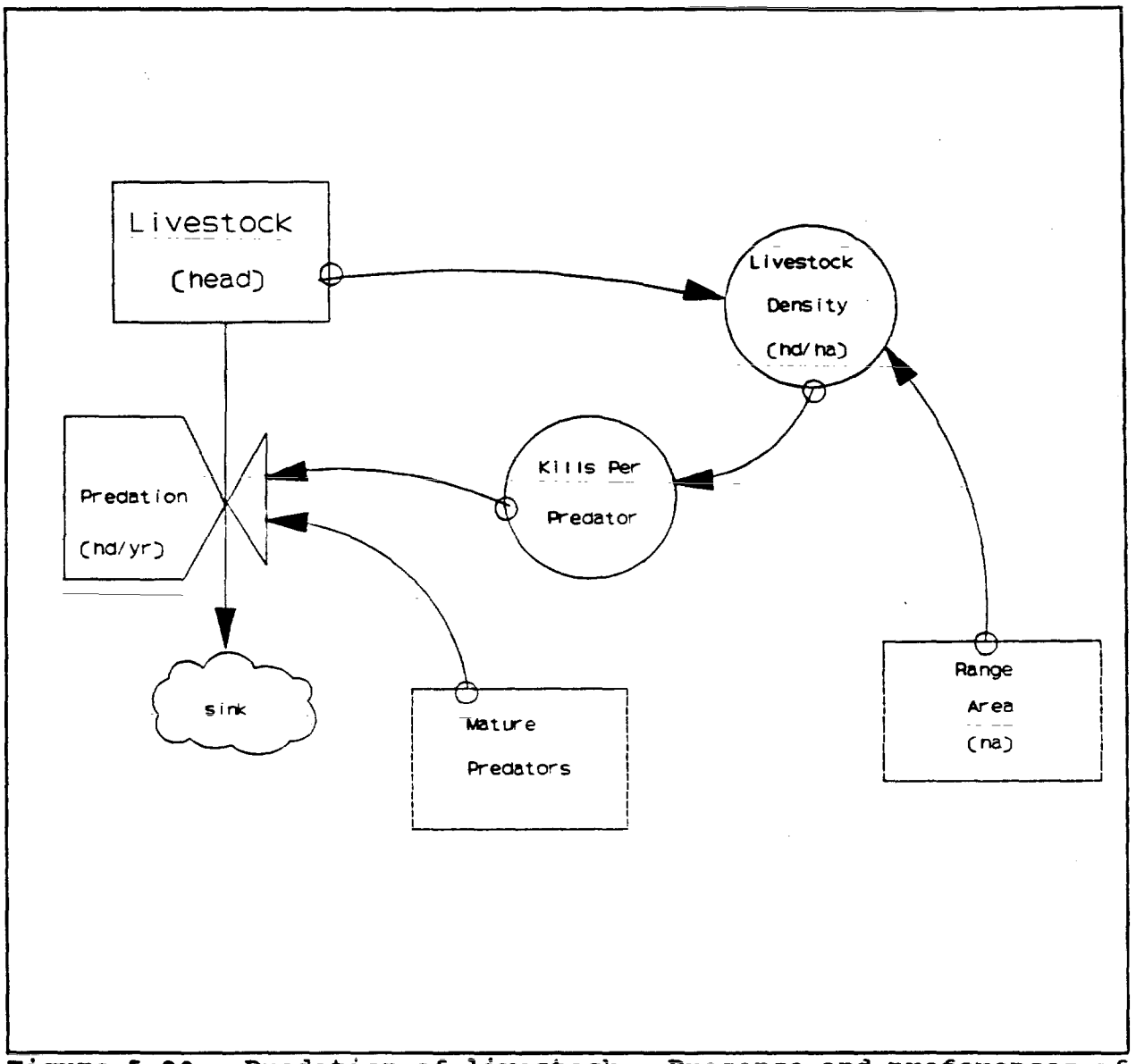


Figure 5-20. Predation of livestock. Presence and preferences of predators and density of prey set the kill rate.

Livestock Average Weight. A key indicator of livestock condition is weight. Average weight is also an indirect indicator, as well as birth fraction, of the range condition. Lower average birth

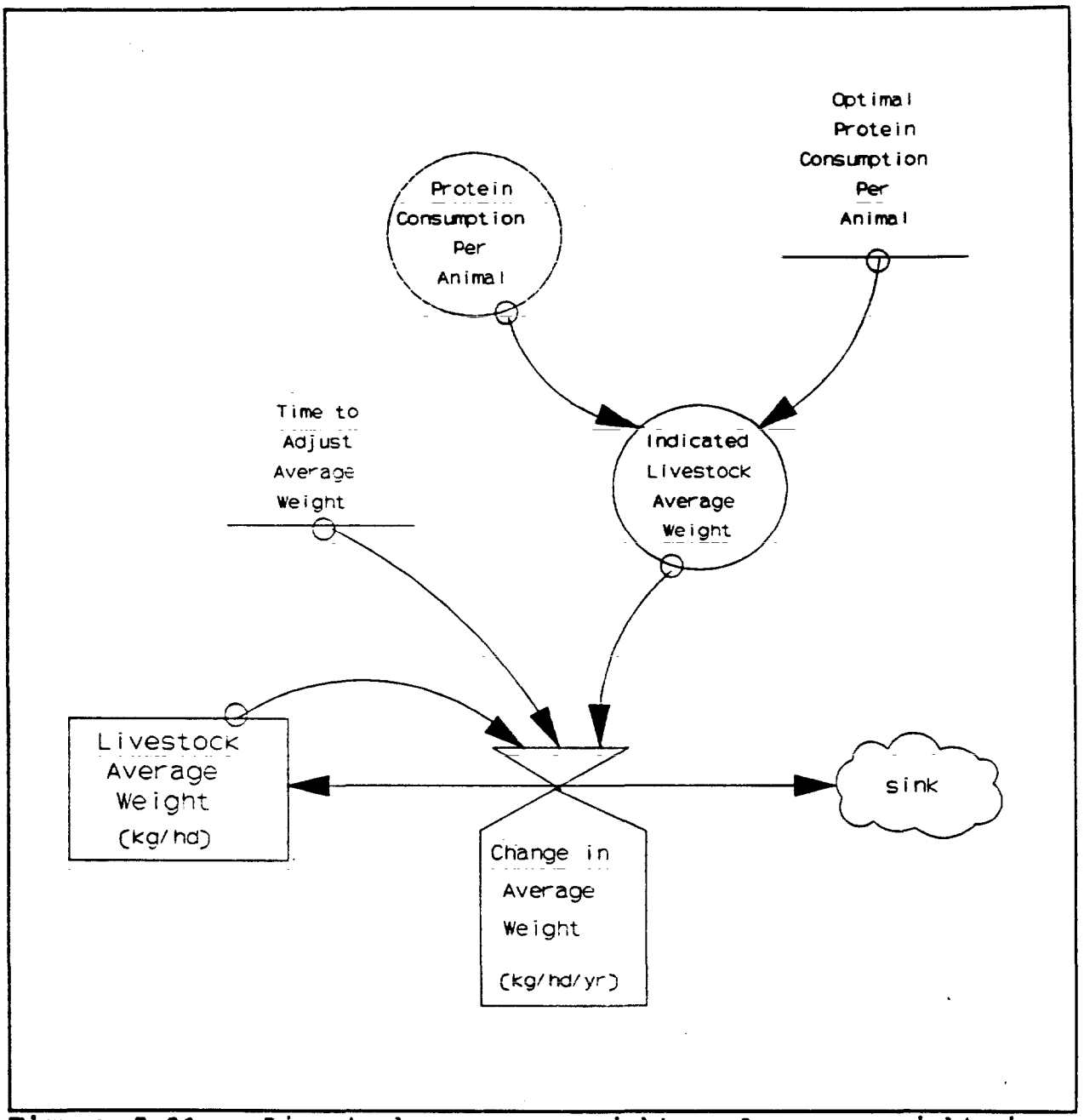


Figure 5-21. Livestock average weight. Average weight is a function of protein consumption, which reflects forage quality and availability.

fractions and weights are reflections of poorer nutritional status of the herd. Throughout a season, ranchers often track weight gain to see how well the herd is doing.

We chose to look at the average weight of the three livestock classes on an annual basis because the model has a long time-frame. An average weight at or close to the optimal weight for the class demonstrates good herd and range condition, while lower average weights indicate a problem. During periods of drought or range degradation average weight will decline. The model estimates an <u>indicated</u> or instantaneous value for average weight based on current protein consumption (See Figure 5-21). The average herd weight is adjusted over time to the longer term changes.

5.3.4 Wildlife Submodel

Five types of wild animals are represented in the wildlife submodel, four ungulates categories and one predator.

- Large and Small Grazers. These animals eat primarily grasses, competing directly with cattle when they are present. Large and small animals are disaggregated between grazers and browsers because of their differences in consumption, birth rates, mortality, etc. Zebra, wildebeest, tsessebe, roan, and sable are representative of large grazers. Warthog and reedbuck are examples of small grazers.

- Large and Small Browsers. Browsers consume relatively larger amounts of trees and shrubs than do grazers. These categories are somewhat artificial because grazers do not strictly eat grass, and browsers do not strictly eat browse. The model has the capability to show mixed preferences even though the categorization of the wild ungulates may not suggest it. Giraffe, eland, and kudu are large browsers, and bushbuck, duiker, impala, and klipspringer are small browsers.

- Predators. This category is modeled in a fairly simplistic way. The presence or absence of predators is important to livestock as well as game managers. However, because their numbers tend to be small relative to the other wild animals, and their direct impact on the range resource is small, this lack of detail is justified. Leopard, cheetah, and lion characterize this wildlife category (See Figure 5-30).

Wild ungulates. A mature and immature population is represented for each of the four animal categories (See Figure 5-22) because there are large differences in the rates of predation and natural mortality for the two groups. In addition, immature animals are usually not hunted or slaughtered.

Immature animals increase from births and decrease due to predation, natural mortality, and maturation. The only source for mature animals is maturation; we have assumed that buying and

selling live animals will not occur in significant numbers to merit modeling. There are four sinks for mature animals: natural mortality, hunting and poaching, slaughter for market, and predation.

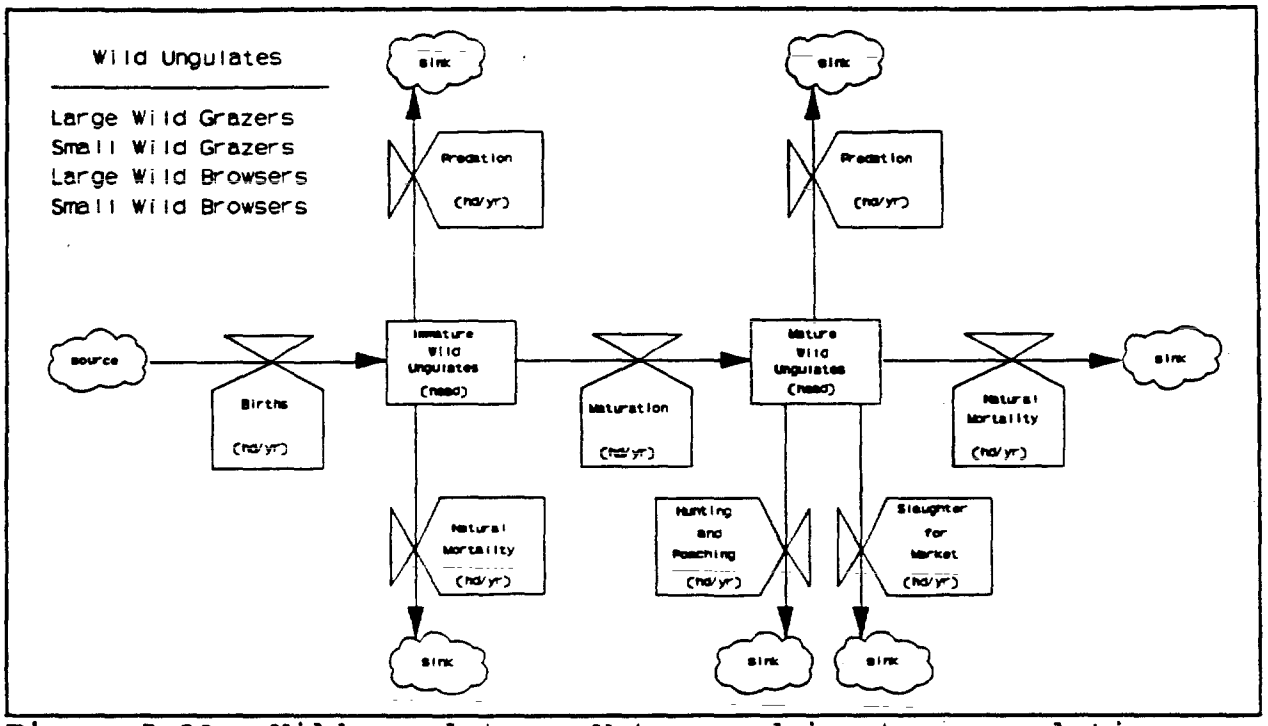


Figure 5-22. Wild ungulates. Mature and immature populations are modeled for four types of ungulates: large and small grazers, and large and small browsers.

Wild Ungulate Births. In many aspects of reproduction, nutrition, and mortality, all ungulates are generally the same and can be modeled as such. There are few structural differences in the factors that determines births for cattle and the four wild ungulate categories (See Figures 5-16 and 5-23).

While the structure may be generic, the parameters that determine the behavior are not. Each category exhibits different requirements and preferences for protein and forage consumption, maximum birth fractions, and rate of fall-off in births when protein consumption is constrained. The maximum birth fraction for wild ungulates is defined slightly differently than for livestock, because the herd fraction that is female must be considered.

Wild Ungulate Natural Mortality. Nutrition plays the primary role in the natural mortality of wild ungulates (See Figure 5-24). Unlike livestock, wildlife species are native to Africa, and are better adapted to their harsh environment and are more able to handle the stressful climatic regime. Most wild ungulates require relatively less free-standing water than do livestock, and some can get what they need directly from the forage they consume (see Chapter 4). Compare Figure 5-24 with Figure 5-17, natural mortality of livestock, where precipitation factors into morbidity.

Both livestock and wild ungulates are subject to occasional disease outbreaks which increase mortality. We have chosen to treat these as random events that are beyond the control of the ranch manager. The exception is the set of diseases caused by ticks and controlled by dipping. For wildlife however, dipping is certainly not an option. In most countries cattle dipping is regulated by law.

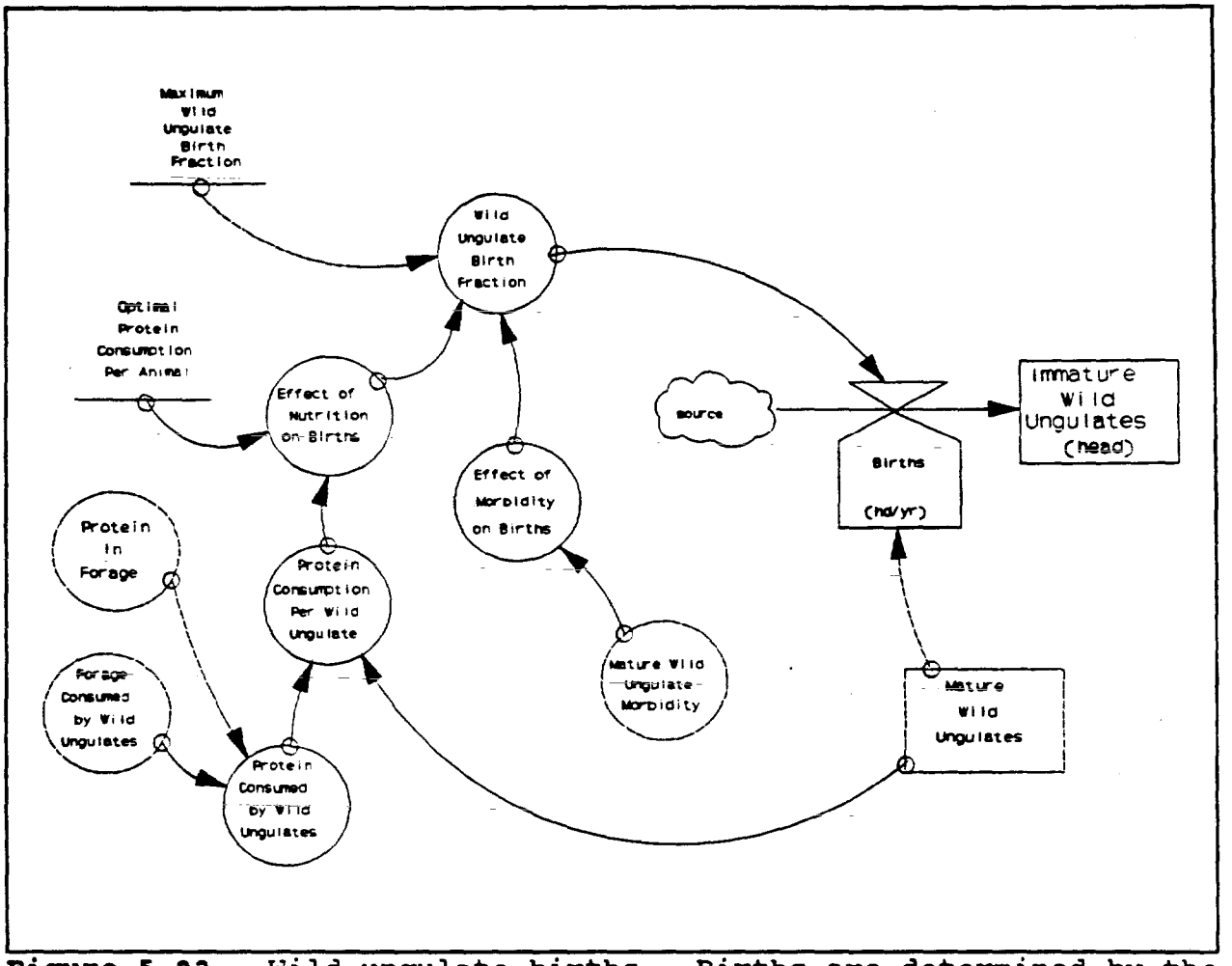


Figure 5-23. Wild ungulate births. Births are determined by the stock of mature animals and maximum birth fraction, which may be limited by nutrition and morbidity.

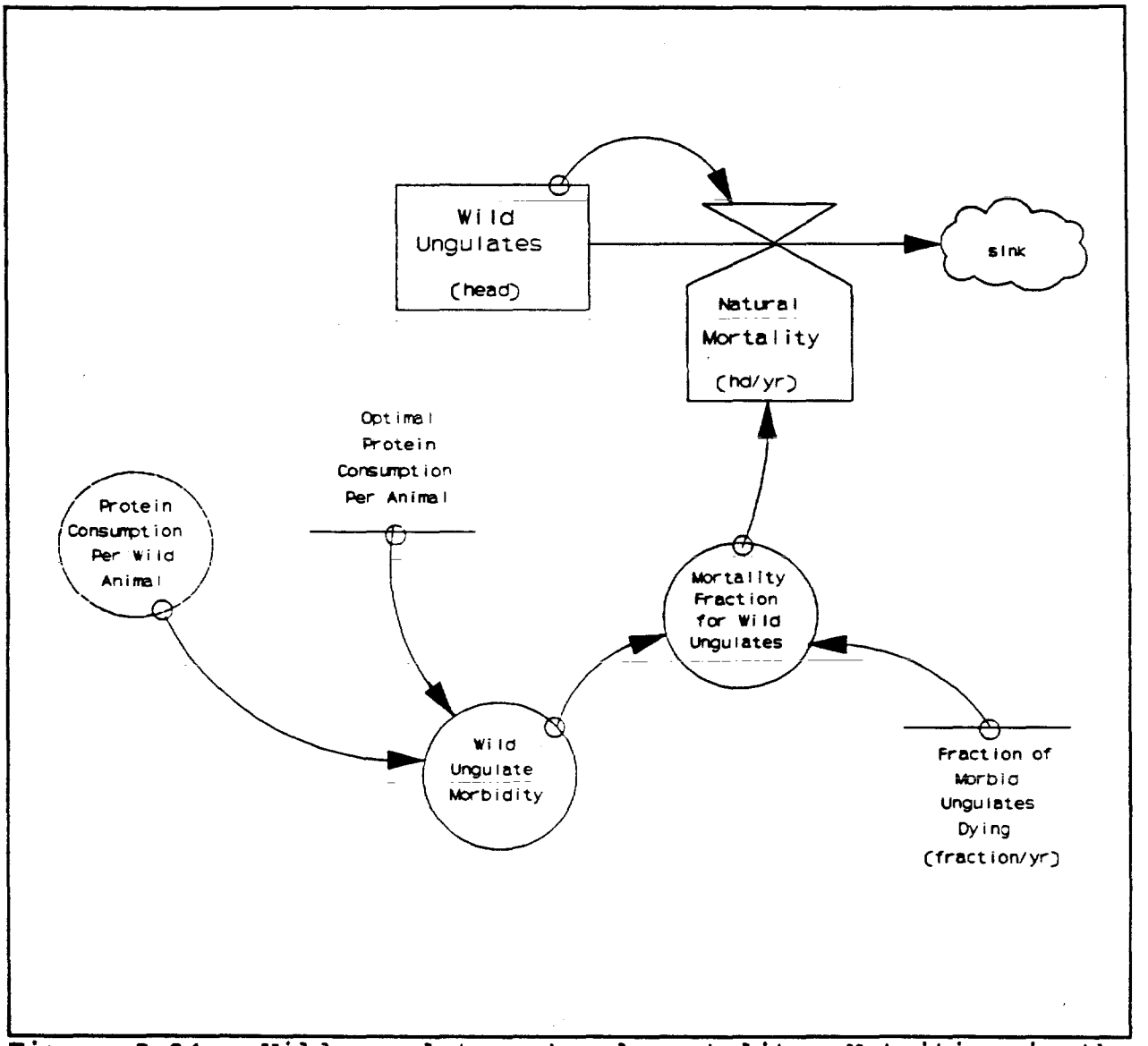


Figure 5-24. Wild ungulate natural mortality. Nutrition is the primary determinant.

Predation of Wild Ungulates. Wild ungulates on game ranches are seldom, if ever, protected from predators by herders. Even

fencing does not provide much protection because many animals can easily jump them. Mortality from predation can thus be very significant.

The predator population is the first and primary element in the predation rate. Predator preference is an important determinant of which wild ungulates will be affected by their presence. Smaller and younger animals are usually easier prey than their larger and older counterparts, and can suffer particularly severe losses. Additionally, some predators such as cheetah, prefer to eat freshly killed animals, whereas others like lions or hyenas will scavenge. These factors, along with prey availability as determined by density, indicate the kill rate per predator for each type and age class of wild ungulates. This kill rate can then be adjusted by the morbidity of the wild ungulate populations because morbid animals are more susceptible to predation. Compare predation of wild ungulates, Figure 5-25, with predation of livestock, Figure 5-20).

Wild Ungulate Maturation. The maturation of the immature wild ungulate populations is modeled in a simple and straightforward manner. Since immature animals are not slaughtered or sold, all the animals that do not die mature in a time period characteristic for the species (See Figure 5-26).

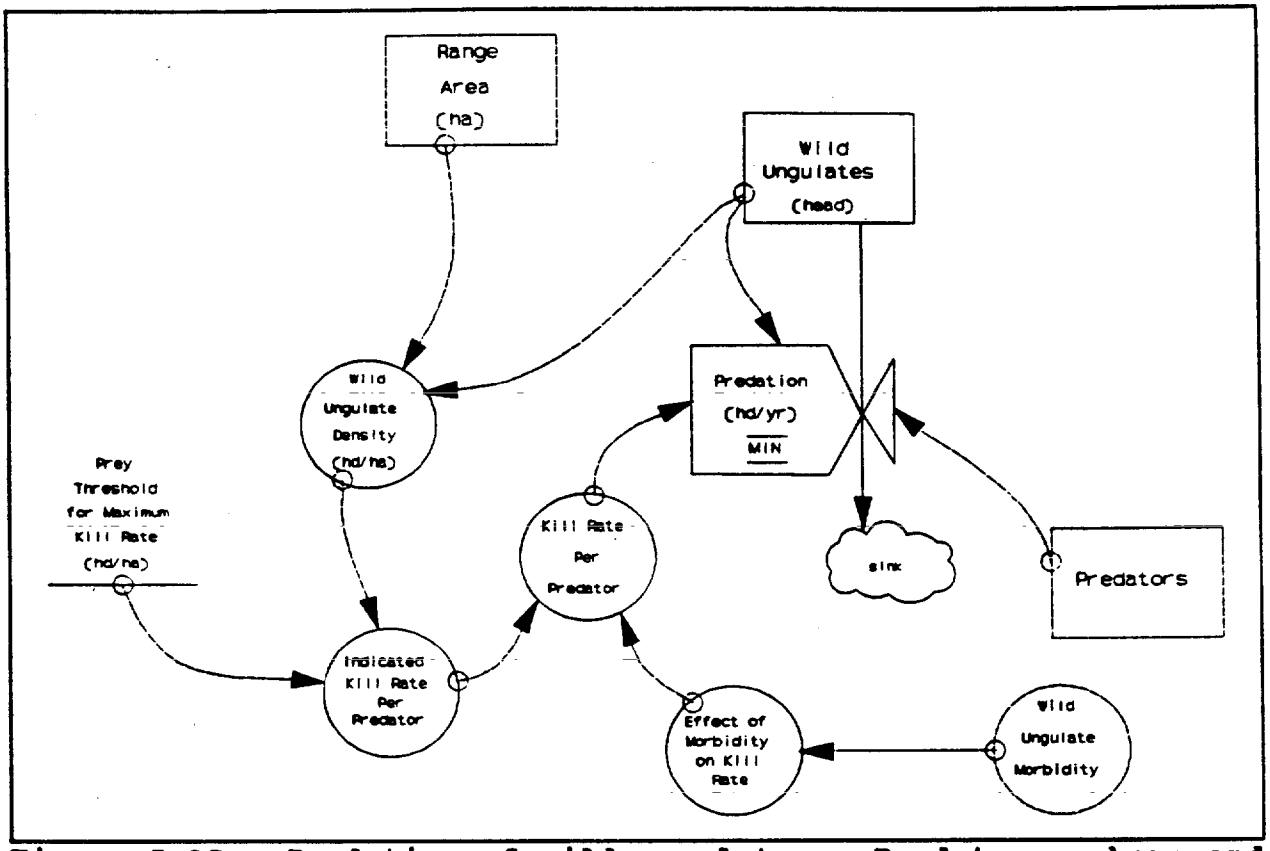


Figure 5-25. Predation of wild ungulates. Predator numbers and preferences, and wild ungulate density and morbidity are the key factors.

Hunting and Poaching of Mature Wild Ungulates. While hunting and slaughter for market represent sources of economic gain for the game rancher, poaching wild ungulates is an economic loss. Determining these uses of the animals can be extraordinarily complicated, encompassing many factors which are beyond the boundaries of the ranch and the control of the rancher. The causes of poaching can include drought, the economic and nutritional well-being of ranch neighbors, attitudes concerning

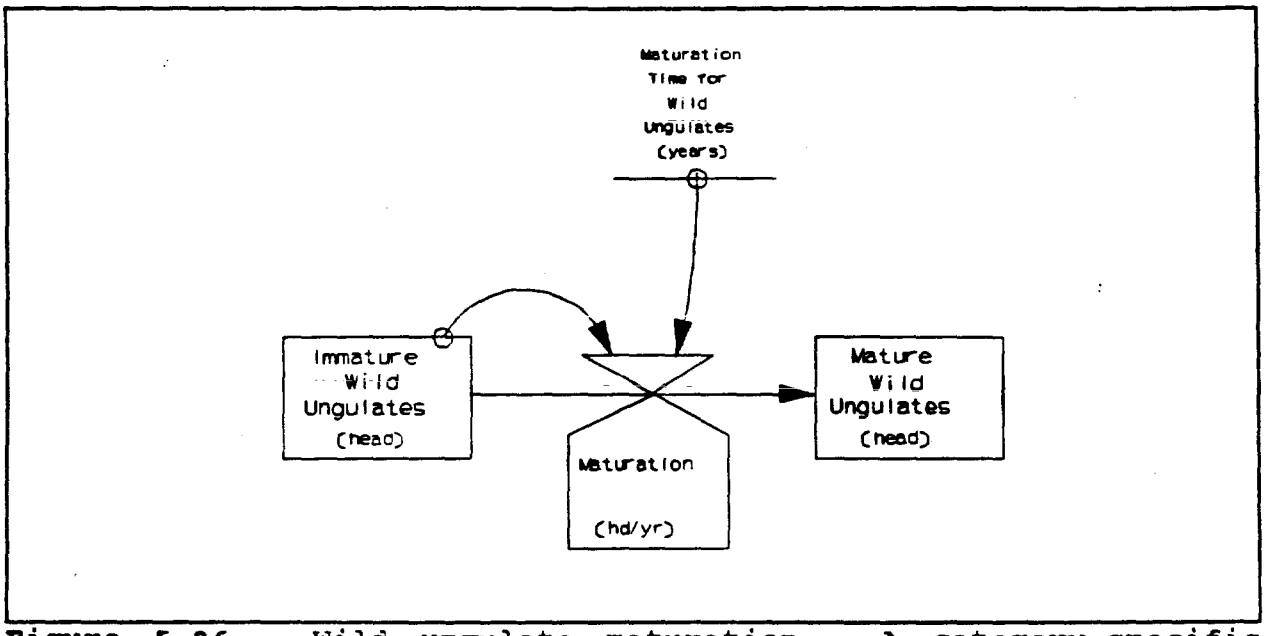


Figure 5-26. Wild ungulate maturation. A category-specific maturation time as well as the stock of immature animals determines the rate.

resource ownership, law enforcement, and prices. All these factors are lumped into a poaching fraction which reflects, but does not explicitly capture, these factors (See Figure 5-27). Similarly, the ability to attract hunters for safaris is influenced by international perceptions about safety and civil strife, prices, marketing, and reputation. Clearly, these factors are too complex to model here in any detail. It is sufficient for the purposes of this analysis to capture the number of hunters by means of an exogenous function, here a ramp, which only requires an initial number of hunters and an annual growth rate, which could be positive, negative, or zero.

The kill rate for hunters can then be determined from the lesser of the desired kill rate per hunter for each category of

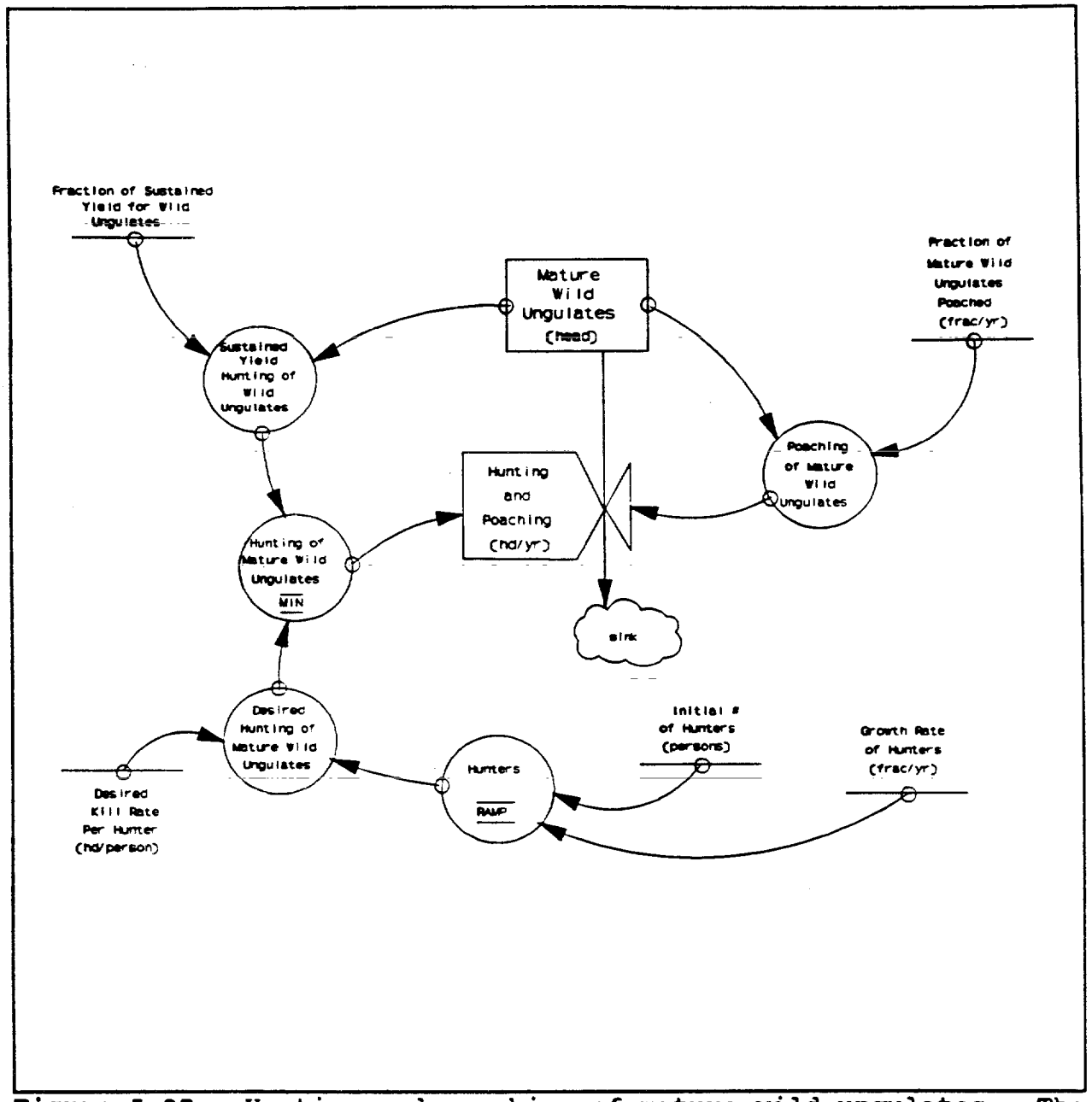


Figure 5-27. Hunting and poaching of mature wild ungulates. The poaching fraction and number of hunters is exogenously determined. Hunting is limited by sustained yield for trophy quality.

ungulate multiplied by the number of hunters, and the sustained yield for each mature population of wild ungulates. Limiting the hunt to sustained yield ensures that the wild ungulate population

will not be overharvested and the trophy quality will be maintained.

Slaughter of Wild Ungulates for Market. Historically, the prime revenue generator for wildlife ranchers has been safari hunting. Slaughter of game animals satisfies small local markets including up-scale restaurants and poorer people in need of an inexpensive protein source. Certain animal categories, particularly small browsers, must be culled in any case because in many places there are too few predators to effectively control the populations and prevent explosive growth.

It is possible that significant market expansion for venison could occur, especially in countries outside Africa, and at higher prices. The factors that could induce this are outside the purview of most game ranchers, who must simply accept or reject, and not determine, the price of and demand for their product. Many factors which operate outside the rancher's control, such as veterinary regulations and consumer preferences, are lumped in the model variable maximum wild ungulates slaughtered. This limit reflects supply and demand constraints because the capture and slaughter of wild animals is more difficult and requires greater investment than the slaughter of livestock. The maximum slaughter rate is a ramp function with exogenous values for the initial maximum and the growth rate (See Figure 5-28).

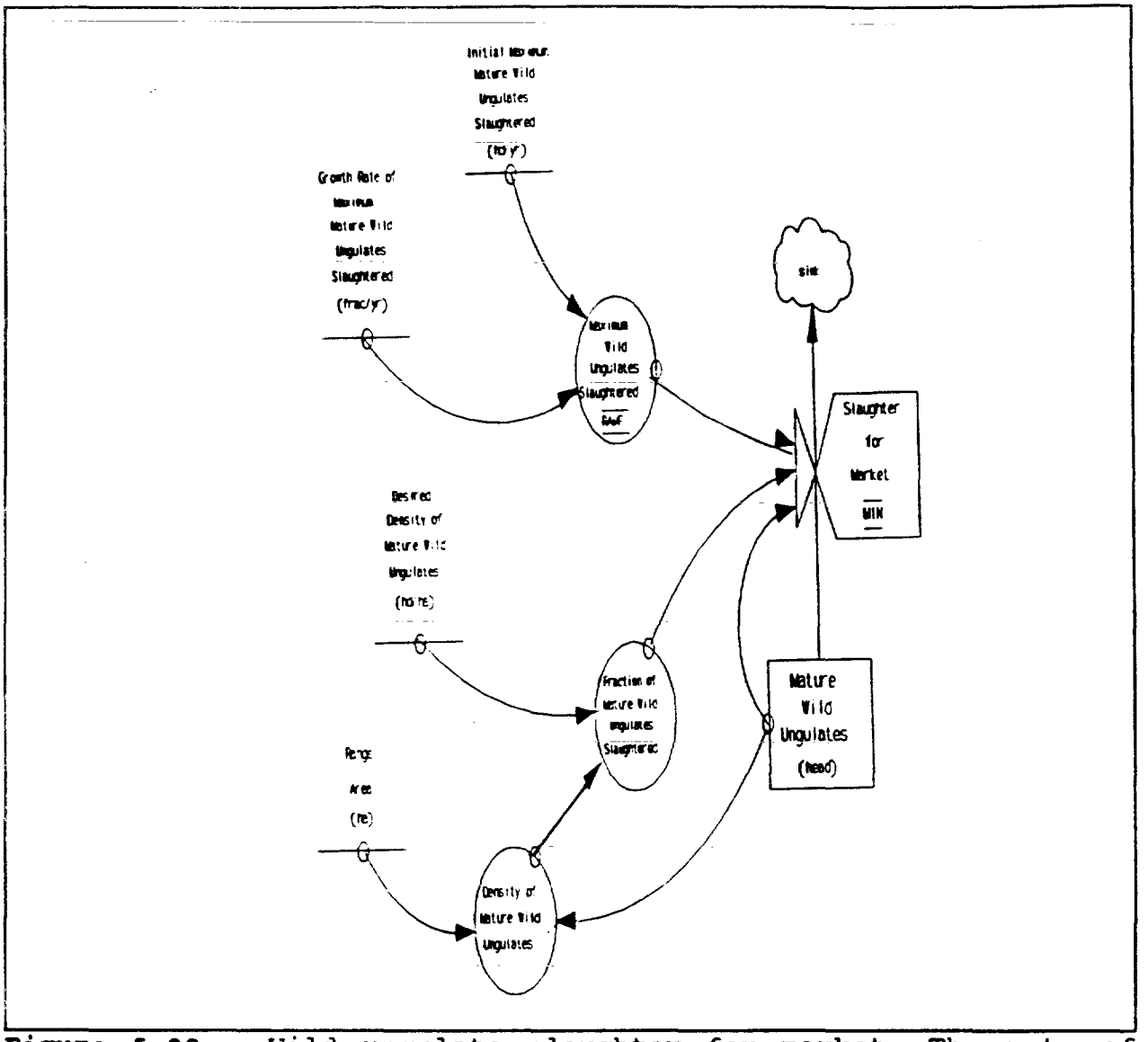


Figure 5-28. Wild ungulate slaughter for market. The rate of slaughter cannot be greater than an exogenously set maximum, which is meant to reflect demand and capability limits, or the rate desired by the rancher for stocking purposes.

The slaughter rate is limited by the maximum slaughter rate or the desired harvest as determined by the density of each category and the rancher's preference for harvesting. The model structure fixes an explicit goal for the density of each wild ungulate category. This desired density is compared with the

actual density and a fractional harvest rate for each type of wild ungulate. This fractional harvest rate takes into account the natural reproductive capability of the animals, as well as their relative value as trophies or meat. Some categories of animals are seldom, if ever, hunted for their meat.

Wild Ungulate Average Weight. Just as livestock average weight is an important indicator of range condition, so too is wild ungulate average weight. In addition, the average weights of both domestic and wild ungulates is necessary to estimate the dressed weight, from which the income from meat sales is calculated (See Figure 5-29).

The average weights for each mature wild ungulate population are adjusted according to nutritional adequacy. The dressed weight is a function of the average weight. Dressed weights are characteristic of the animal type, but percentages are generally higher for wild as opposed to domestic ungulates. These dressed weights decline as average weights fall.

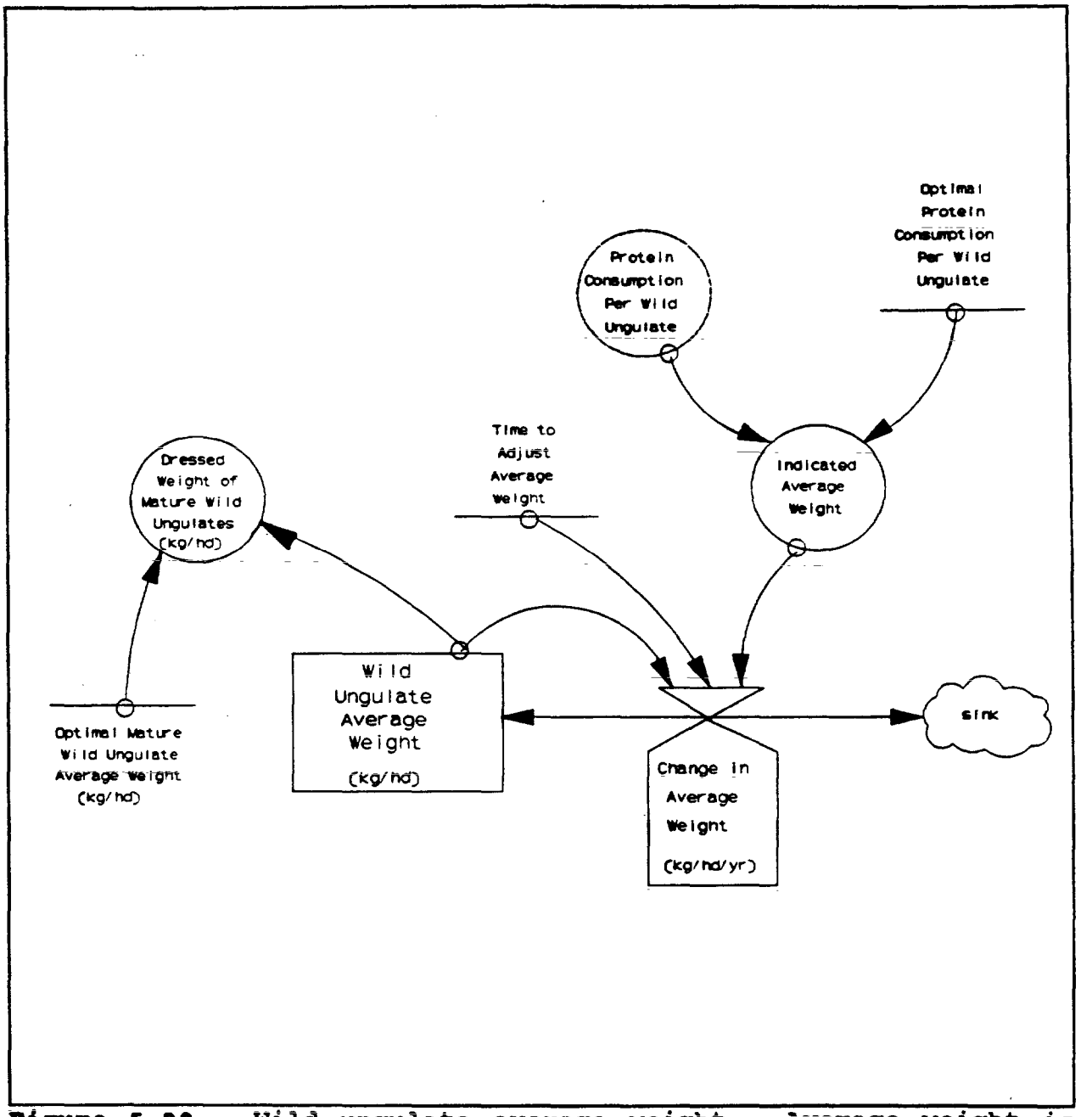


Figure 5-29. Wild ungulate average weight. Average weight is determined by forage quality and availability.

Predators. The model structure for predators is simple and uncomplicated. Predators are an important part of the range

ecosystem, but in many parts of the world, they have been, or are being replaced by humans. In essence, this is what ranching is all about -- utilizing the natural productive capacity of the range/ungulate interactions to provide human livelihoods, whether they be for nomadic pastoralists or commercial game farmers. The simplicity of the model structure reflects this.

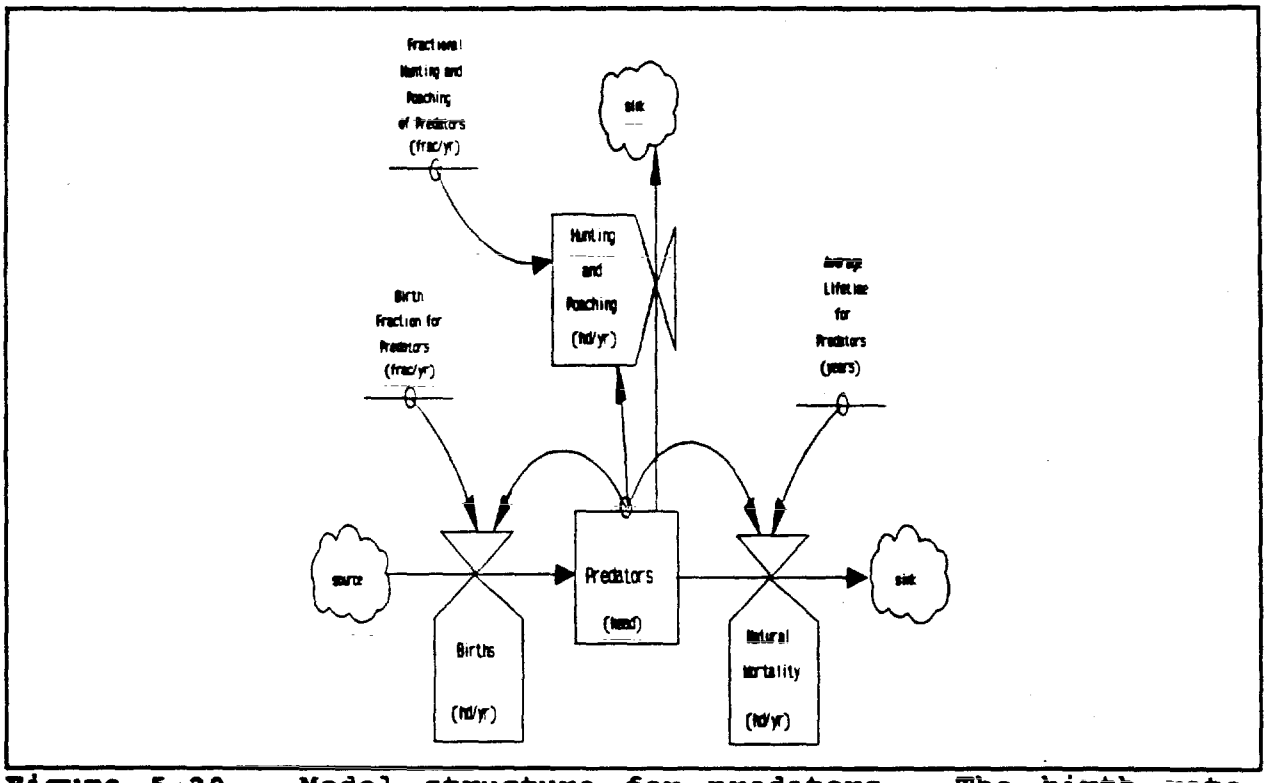


Figure 5-30. Model structure for predators. The birth rate, natural mortality rate, and rate of hunting and poaching are represented.

One stock of predators is modeled with three corresponding rates: births, natural mortality, and hunting and poaching. Each of these is determined by using a constant for birth fraction, average lifetime, and fractional hunting and poaching (See Figure 5-30).

5.3.5 Ranch Accounting

For a person who is attempting to manage a resource for profit, it is important to gauge not only the ecological impacts of a policy or plan, but also the economic effect. We have structured a ranch accounting component of the model to track income and expenses.

Net income for the livestock operations is the difference between gross income and annual expenses (See Figure 5-31). Gross income is the sum of income from livestock sales, milk sales, and change in herd value. The change in herd value is the difference between the herd value for the current and previous years.

Annual expenses are the sum of several factors assumed to be constant. These include salaries and wages, operations and maintenance, depreciation, and several other expenses not shown in Figure 5-31, including administration, rentals, livestock transport, and utilities, etc. These may or may not be used according to the operation. The only cost assumed to be variable is livestock purchases, which is calculated from the estimated purchases, the optimal weight, and the purchase price.

The accounting for the game operations is simpler, with only constant costs assumed for expenses. Gross income comes from self-run safaris (on the ranch), safari concessions (off the ranch), and wild ungulate meat sales (See Figure 5-32).

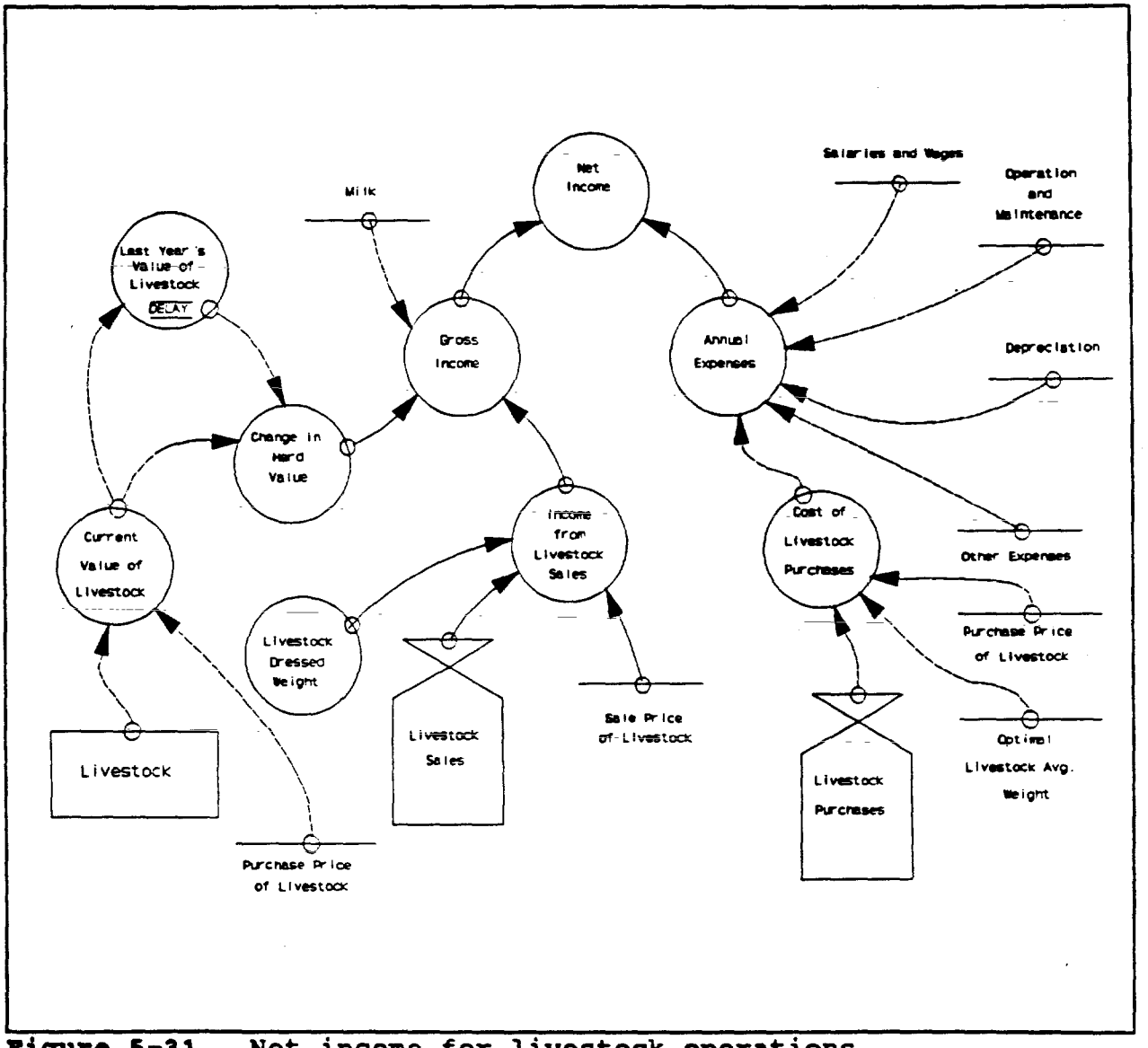


Figure 5-31. Net income for livestock operations.

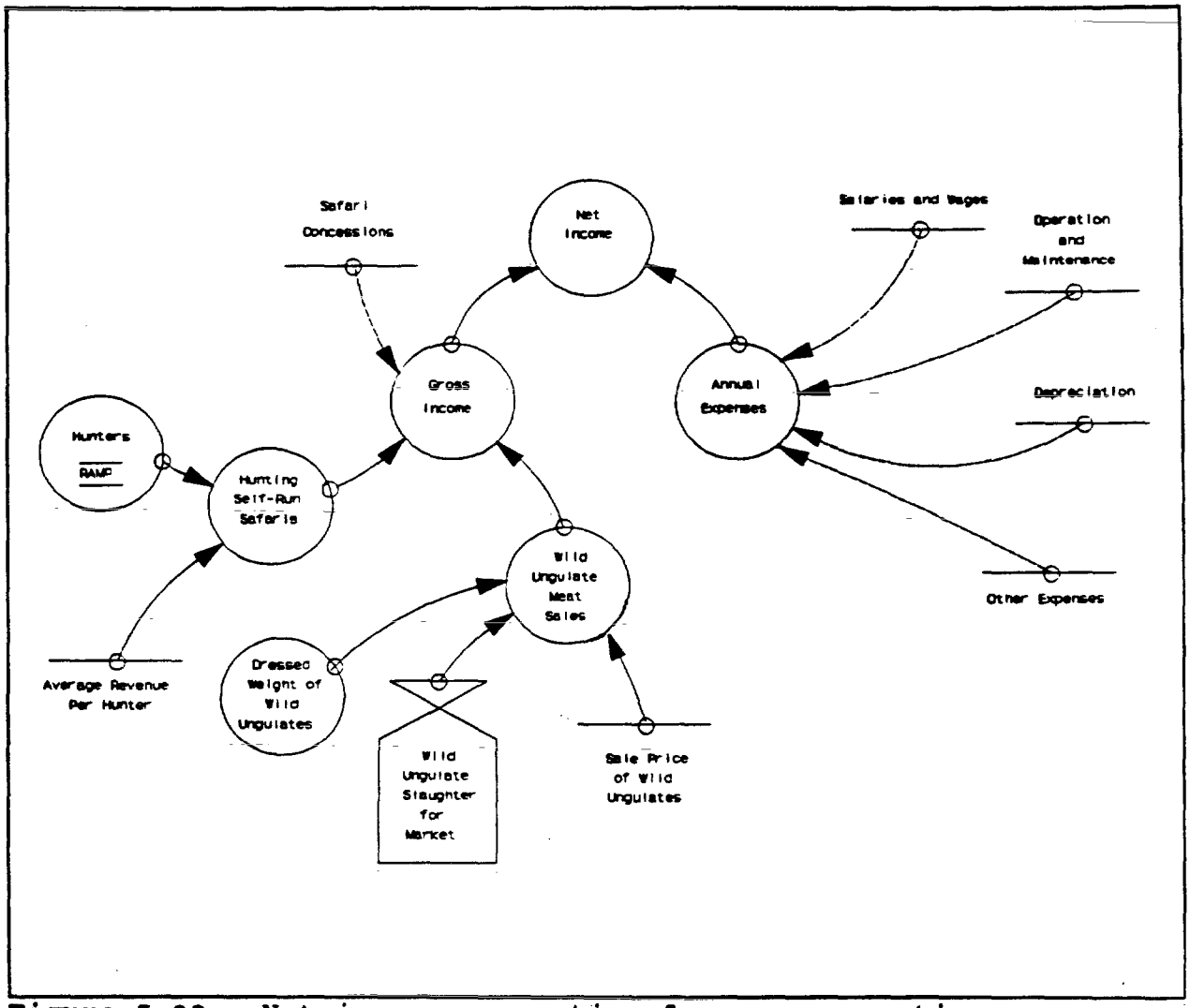


Figure 5-32. Net income accounting for game operations.

Chapter 6

VALIDATION, POLICY TESTING, AND SENSITIVITY ANALYSIS

		Page
6.1	Introduction	268
6.2	Validating the Range, Livestock, and Wildlife Model	269
	6.2.1 Structure and Testing at Extremes	270
	6.2.2 Model Calibration and Validation	272
6.3	Model Behavior	285
6.4	Testing Management Options for Livestock Operations	293
6.5	Parametrical Sensitivity Analysis	310
6.6	Conclusion	322

6.1 Introduction

This chapter presents the validation, policy testing and sensitivity analysis of the model described in Chapter 5. We provide some measure of confidence in the model and its use for policy testing by presenting a successful validation of the model and explaining how this was accomplished.

Second, a detailed explanation of the system we examined and its behavior provides an understanding of how an actual range, livestock, and wildlife system works and why. As the system degraded, we looked at the likely causes of this degradation during the time period we examined. A series of policy tests demonstrated several managerial options for mitigating or entirely eliminating the undesired impacts. These policy tests compared and contrasted these outcomes with the outcomes from the base case, and explained the processes which generated the differences.

Finally, the results of a sensitivity analysis using the model are presented, which provides an indication of the feedback and parameters most important in determining system behavior. This information would be particularly useful to those interested in prioritizing the collection of information for management or research.

6.2 Validating the Range, Livestock, and Wildlife Model

Chapter 3 described three methods of testing the validity of models: a review of the structure by experts, testing the model at extremes, and testing the results against historical data. We used these methods and can report that the model passed all three tests satisfactorily.

Although we can increase our confidence in the model and its utility, our previous caution bears repeating: models cannot be shown to be true, but can only be shown to be untrue. This may sound somewhat confusing and appear to be an example of the silly semantic arguments of modelers, but in fact, this is a crucial point for the proper use of any model or computer program.

If a model could be shown to be strictly valid for all circumstances, there would be no need to issue cautions such as we are doing here. However, it is not possible to consider every circumstance or model every detail in order to faithfully represent the system for every case in which it may be used. If it were, the model would be as complicated as the real system, and just as unfathomable. Additionally, any good computer programmer will tell you that it is impossible to know if there are no bugs in the program, only to know when there are. Thus, no matter how rigorously a model is tested, there is always the possibility for some error to appear.

Models are best used to explain and understand the systems they focus on, and that is our primary purpose. Models should never be treated as inexplicable black boxes used to accurately project the future, or as some sort of crystal ball or time machine. The reader should continually question, probe, and scrutinize the assumptions and results we present. Models can best be used as aids to human understanding and guides for human judgement, and should never be used as substitutes for these, or as excuses to relinquish the burden of decision-making.

6.2.1 Structure and Testing at Extremes

Throughout the modeling process we have taken many opportunities to explain the structure of the Range, Livestock, and Wildlife model to qualified experts. In fact, to a degree, such experts created the model during the workshops. A number of changes and adaptations resulted from these reviews, particularly at the early stages of the process, but these changes became fewer and fewer. Simple differences of opinion, of course, preclude a complete consensus. The best we can say that reviewers' comments have been considered.

The sensitivity analysis will report on testing the model at extremes. This type of test "kicks the model around" to see if it responds in a reasonable way. Model runs are made to simulate situations which in the real world are highly unlikely, if not impossible. If the model responds well it is said to be "robust." If, on the other hand, the variables take on impossible

values, such as negative numbers of cows, births, or deaths, then the model is invalidated and the error found and corrected. In this way structural and programming errors may be discovered. This process of invalidating and correcting the model is repeated until no more errors can be found.

6.2.2 Model Calibration and Validation

One of the most critical aspects of model validation is finding an appropriate data base against which to validate. The characteristics of an appropriate one are length (over time), reliability, and consistency (See Chapter 3, Section 3.4.5). Finding such a data base can be rather arduous for any analysis, but it particularly difficult when looking at natural resource use and development in developing countries.

After a rather long search, we were able to find a data base sufficient for our needs at Buffalo Range Ranch, near Chiredzi, Zimbabwe (See Fig. 6-1). Buffalo Range has been run by the same family since the late 1950's, and the ranch records start in 1961. These records are anomalous in that the detail and length is significantly greater than that from any other ranch we could identify. The records span 26 years and contain information for five classes of livestock including head numbers, sales, and purchases, as well as costs and income for the livestock and game operations. Additionally, Child (1988) has collated and analyzed much of these data, and provided his analyses to us.

Working with the reasonable data base from Buffalo Range and the workshop results from nearby Chiredzi, we were able to adapt our existing model to address the goals, problems, key questions, and structure. Not only would we be able to rigorously test the IPT methods, but also examine the relative difficulties and opportunities of livestock and game ranching.

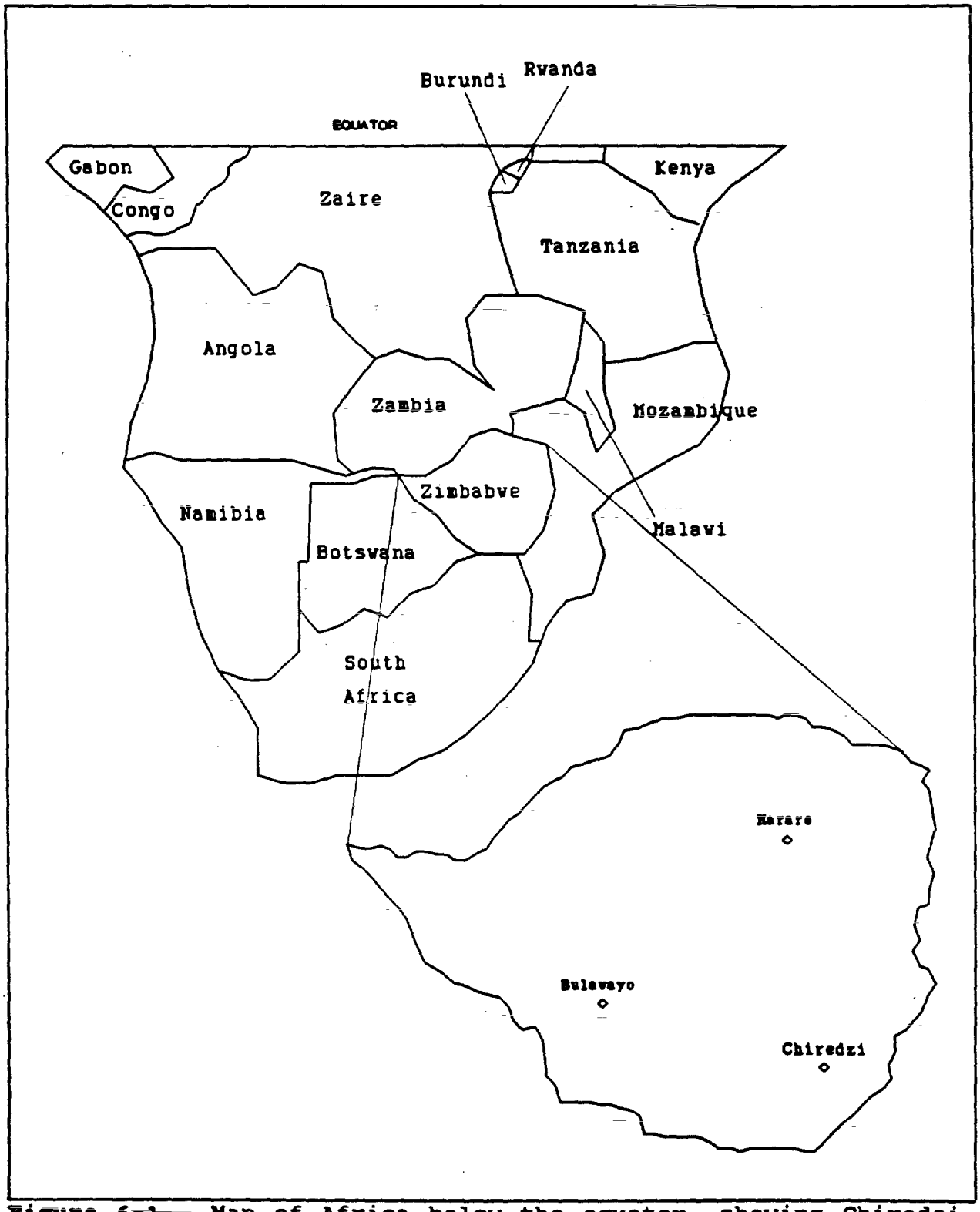


Figure 6-1. Map of Africa below the equator, showing Chiredzi, near Buffalo Range Ranch.

The first steps in the validation process that use the data base define the parameters (parameterization) and begin calibration. In setting the parameters, the data base is used to determine initial values for the main stocks such as head of livestock and wild ungulates, forage, and range area. Additionally, the model must be given data that will let it reflect the site against which it will be validated. These parameters include such things as precipitation, forage productivity, and animal productivity. Many of these numbers had not been identified specifically for Buffalo Range, so we used data from other sites, such as nearby farms or research stations. In a few instances we had to use data from African locations outside Zimbabwe.

In any modeling process, the data quality will range from those with a high degree of accuracy and/or precision, to those of unknown quality. A calibration process is thus required to adjust those parameters which are of poor quality so the model gives the best response. It is assumed that if the model structure is correct and there is a sufficient quantity of good quality parameters, then those of poor quality may be arrived at through the use of the model and historical data.

To calibrate the model the data base must be split in half, the first half for calibration, and the second for validation. If possible, the half saved for validation should contain some

type of disturbance such as a drought, rather than simply straight-line trends, so that the model's response to the disturbance can be judged. The half saved for validation should be put aside, and not used for any part of the calibration exercise or examination by the modeler.

For Buffalo Range Ranch, the June-July rainfall seasons of 1973-74 to 1979-80 were the best in living memory. Every season had above-average rainfall, several seasons by substantial amounts (See Figure 6-2). This time of excellent rains was followed by the worst three seasons of drought in living memory, 1980-81, 1981-82, and 1982-83. Each rainfall season was much below the normal of 556 millimeters per season.

These disturbances are emphasized in Figure 6-3, which shows the three-year running average of the rainfall data. Cycles of dryer than average, as well as wetter than average rainfall seasons are obvious. However, the rainfall seasons from 1973-74 to 1979-80 stand out as being considerably wetter than the average, while the period 1980-81 to 1985-86 is seen to be worse than the usual drought period. We viewed these disturbances as being more than sufficient for a rigorous test of the model.

The data set was split for calibration and validation (See Figure 6-4). Data for 1961 provided initial values for the model. Additionally, the precipitation data for the years 1961 to 1974 were put into the model to enable calibration, and the remaining data set aside. Only one other variable was put into

the model as a time-series input for the model to use in its calculations: the range area for the livestock and game sections of the ranch. This was necessary because the range area, particularly for the livestock section, was anything but constant (See Figure 6-5).

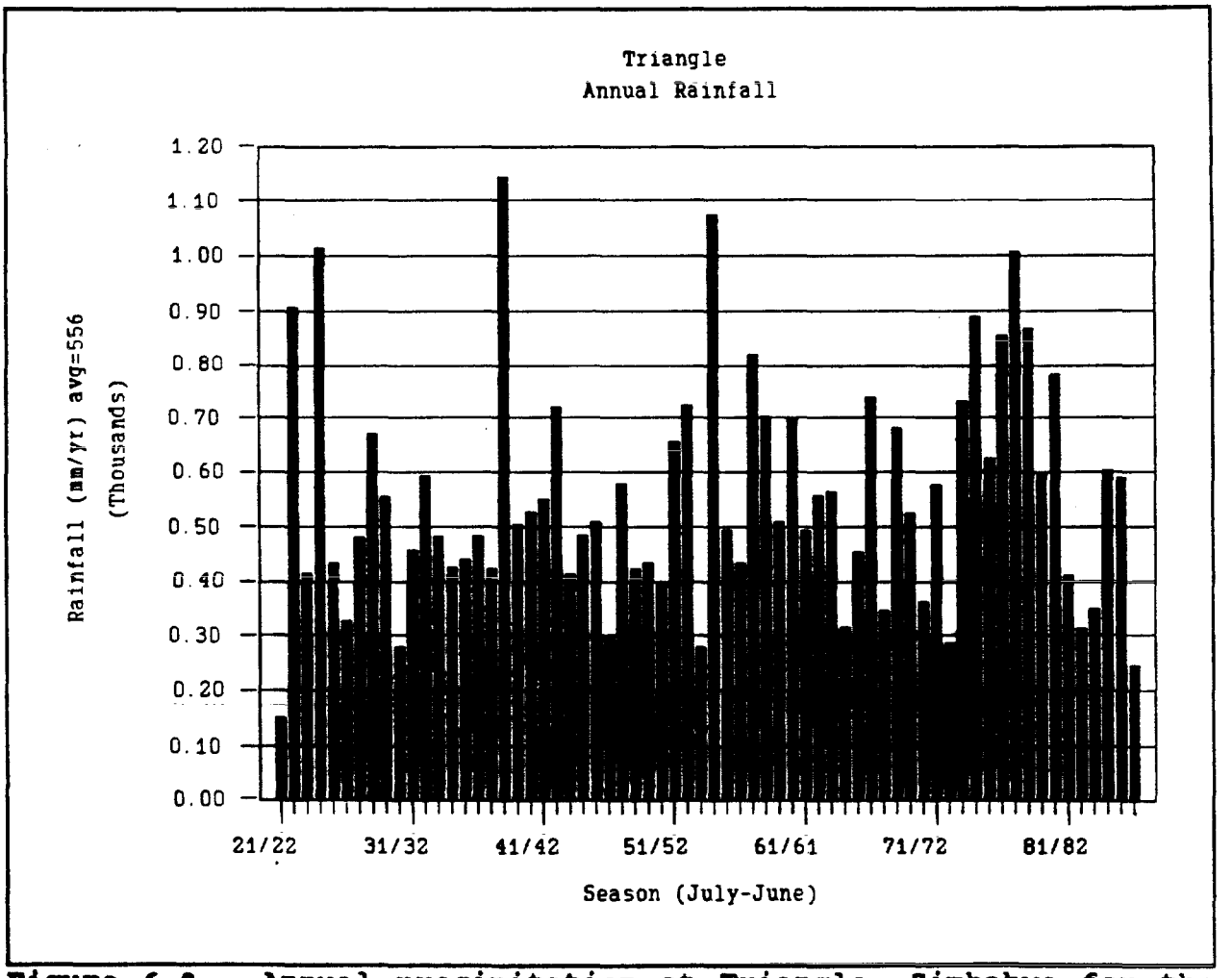


Figure 6-2. Annual precipitation at Triangle, Zimbabwe for the rainfall seasons 1921-22 to 1986-87. Triangle is about 10 kilometers from Buffalo Range. The average was 556 millimeters.

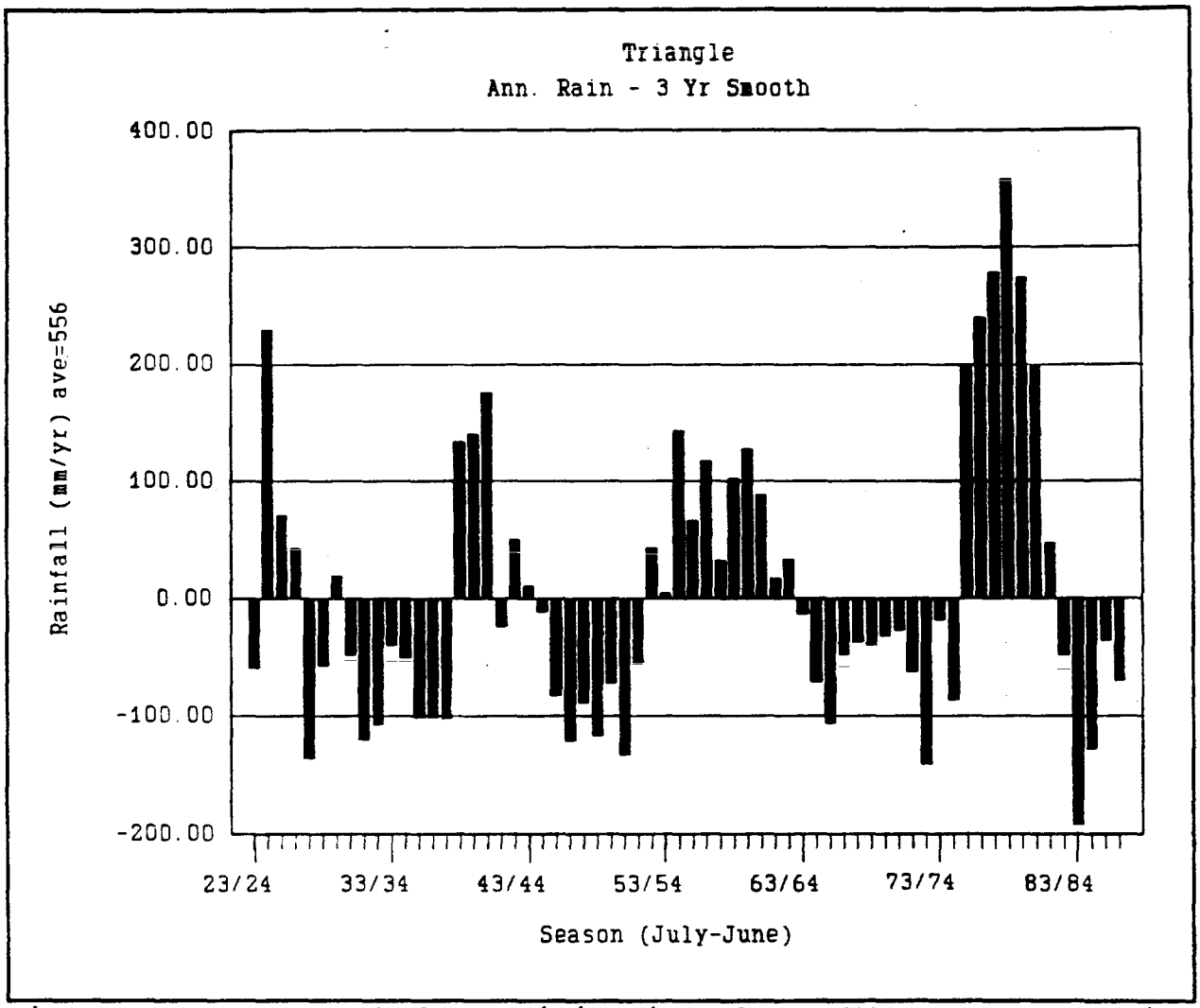


Figure 6-3. Smoothed precipitation data (three-year running average) from Triangle, Zimbabwe. Cycles of good and bad rain periods are obvious, with the last cycle being better and worse than usual.

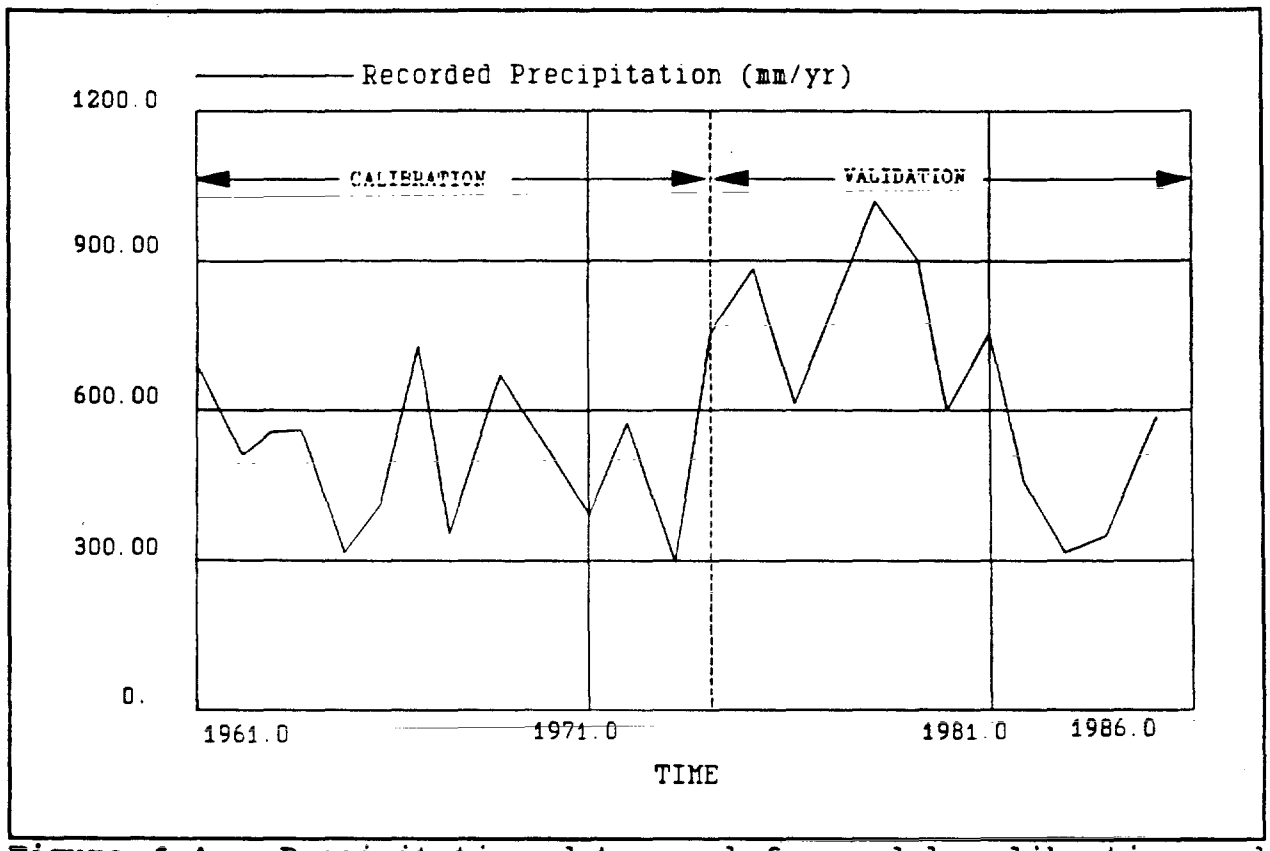


Figure 6-4. Precipitation data used for model calibration and validation.

Validation Results. When the previous processes of debugging, invalidation, testing at extremes, and calibration were completed satisfactorily, we put the data from the second half of the data base into the model and ran it again. Precipitation and range area data were extended as model inputs to 1986, and cattle numbers for the complete data set were entered.

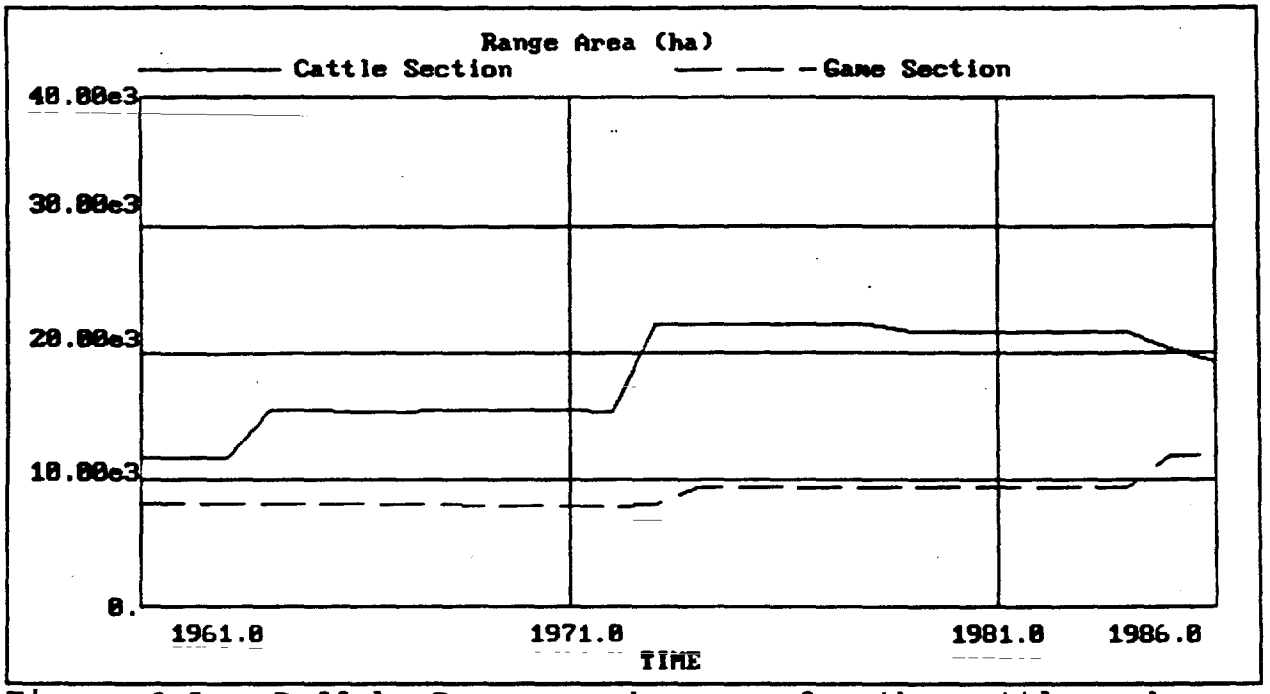


Figure 6-5. Buffalo Range ranch areas for the cattle and game sections.

The three primary variables used for calibration and validation were the numbers of immature cattle, mature female cattle, and mature male cattle. These three groupings reflect a clumping of the five categories used in the Buffalo Range records: calves, wieners, heifers, bulls, and steers. The three groupings of actual data were put into the model, but not used for any calculations. Instead, the actual data were used for comparison with model results (See Figure 6-6).

In general, the models results exhibit a fairly high degree of fidelity with the actual results (See Figures 6-7, 6-8, and 6-9). Of particular note are the results for immature cattle. The model mimics exceptionally well the increase and then

precipitous decline of immature cattle during the good rain years and the following drought years. The model tends to underestimate the number of immature animals during the drought and later recovery (1981 to 1986), most likely because the ranch owners supplied supplementary feed during the drought. The model does not accommodate this practice.

Also of special note is the relatively low accuracy of model results as compared to actual data for mature male cattle, especially after 1974. This result was expected, although not quite to the degree shown after 1974. The more an animal category is subject to speculation and irregular management decisions, the harder it is to reproduce the behavior of that category in the model. Because bulls and steers are either of minimal or no importance to the breeding herd (only one bull is required per twenty-five cows), they are particularly susceptible to speculatory decisions by the ranch manager or owner, who in turn is subject to a host of unpredictable and erratic external factors. As an example, there was a significant drop in mature males between 1968 and 1971 (See Figure 6-9). During this period the owner decided not to keep steers on the ranch. Steer numbers declined from 212 in 1967 to 9 in 1970. This decision to eliminate steers was reversed in 1972 and the steer population increased to 237.

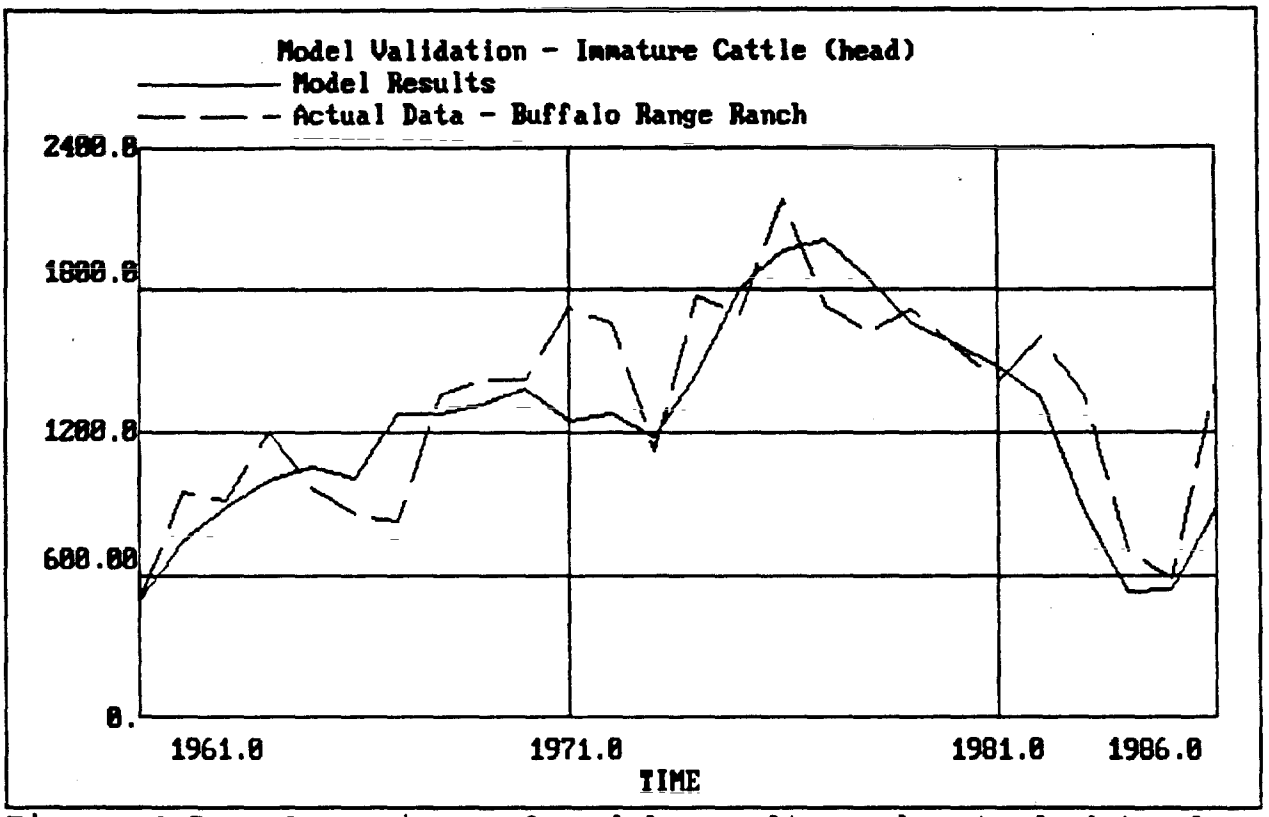


Figure 6-7. Comparison of model results and actual data from Buffalo Range Ranch for 1961 to 1986 for immature cattle (calves and wieners).

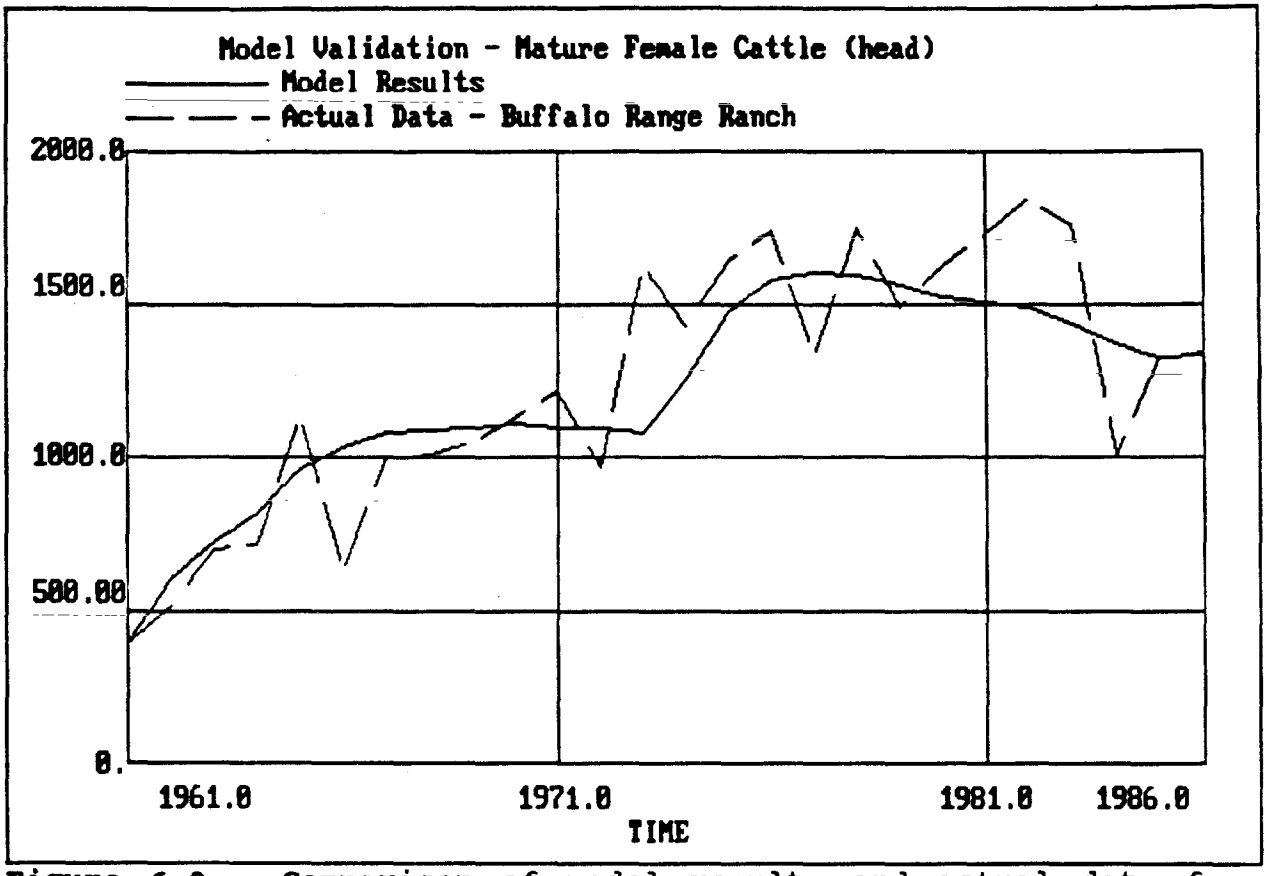


Figure 6-8. Comparison of model results and actual data from Buffalo Ranch from 1961 to 1986 for mature female cattle (heifers).

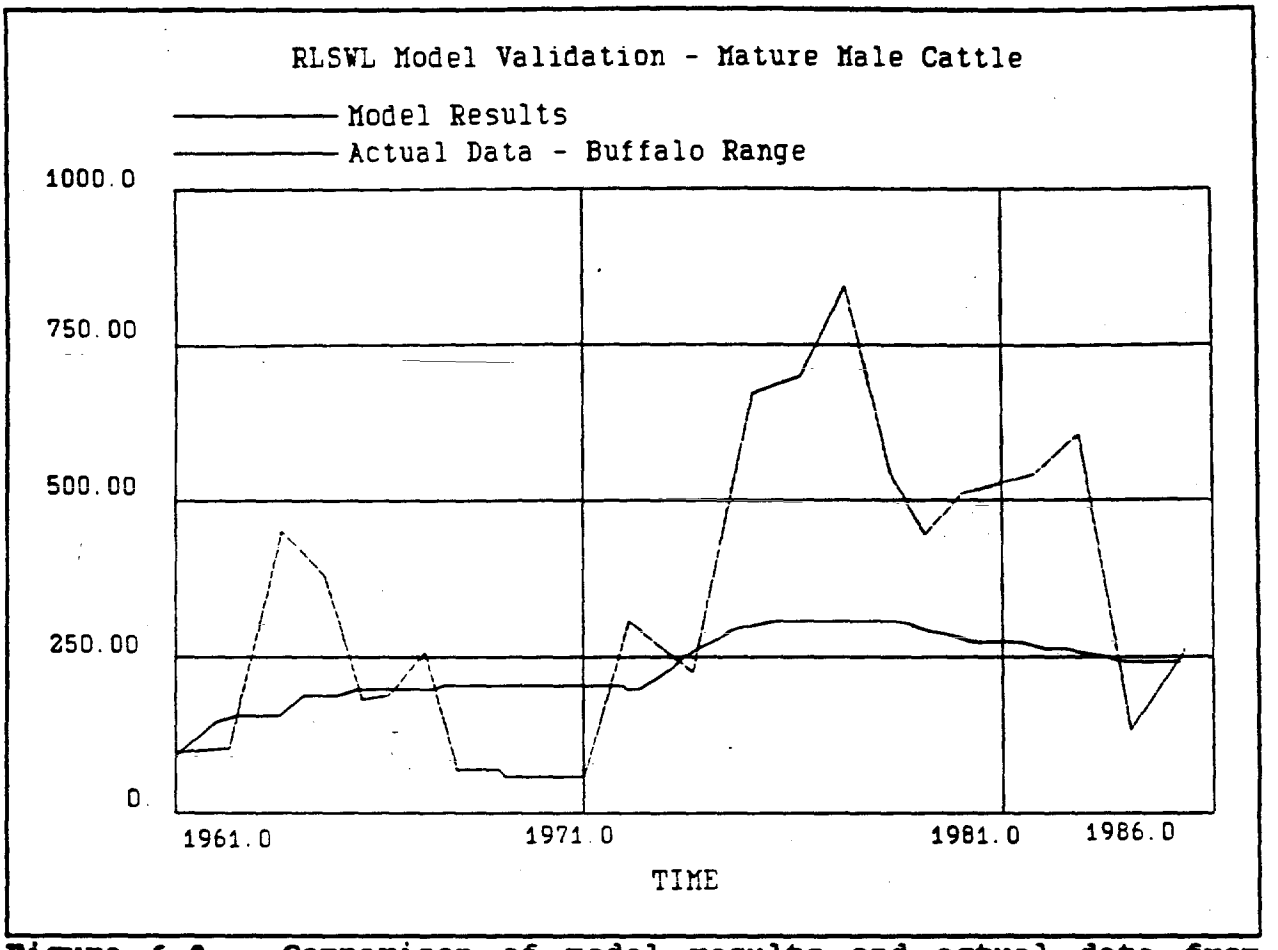


Figure 6-9. Comparison of model results and actual data from Buffalo Range Ranch from 1961 to 1986 for mature male cattle (bulls and steers).

Model results show a higher degree of fidelity to actual data for immature and mature female cattle because these categories are somewhat less subject to speculation, and controlled to a greater extent by regular management decisions and biological processes.

In all the validation runs however, the reader will note that the model behavior is relatively smooth and regular as

opposed to the actual data. Once again, these results were anticipated and we view them satisfactorily. Our purpose in developing the model was to look at long-term ranch management as opposed to short-term decision making. As such, we are satisfied that the model reproduces the trends, and we are not concerned that the model does not capture every peak, blip, trough, or cusp. We did not attempt to make it do so.

A characteristic of models is that they are rigid in their application of decision rules. Rules for making decisions are set by the modeler at the beginning of the simulation and are unyielding. In the real world, this would be a very undesirable managerial characteristic. Good judgment, experience, and flexibility are the cornerstones of good management. Not so with models however, their use (or at least the use of this model), is to test various policies (for example, decision rules), and to examine the implications of those policies. This information can then inform the manager or policymaker, providing greater insight and understanding in the face of a changing, unpredictable world.

6.3 Model Behavior

Up to this point we have not looked into the behavior of the range, livestock, and wildlife system represented by the model and the data from Buffalo Range Ranch. In this section we will discuss what the actual data and validation results show, and explain these through further model simulations. The most important conclusions concerning the ecological changes and herd performance on Buffalo Range Ranch have been previously discussed and confirmed by Child (1988). Some other conclusions and results are based upon the original modeling work, but have also been confirmed in personal communication with Child.

Figures 6-7, 6-8, and 6-9 all show dramatic responses for both the actual data and model results in the cattle populations during the three years of drought in the early 1980's. Upon closer inspection of Figure 6-7, however, the decline in numbers of immature cattle is seen to start well before the drought, during the years of exceptionally good rainfall. This behavior is not the product of increased cattle sales, but instead is the result of significantly reduced herd fecundity. Why would the reproductive ability of the cattle herd decline during the best rainfall years in memory? The short answer is range degradation.

In a simulation of plant biomass on the cattle section of Buffalo Range, there is a very clear and pronounced shift in the grass community, with decreasers and increasers reversing their occurrence on the range (See Figure 6-10). The shift began in

the early part of the run, where decreasers drop during droughts, and do not recover. With less competition from decreasers, increasers become as significant as the decreasers, and become positioned for a fairly dramatic increase when the good rain years begin in 1974. The cumulative effects of overgrazing during the first half of the simulation cause this behavior.

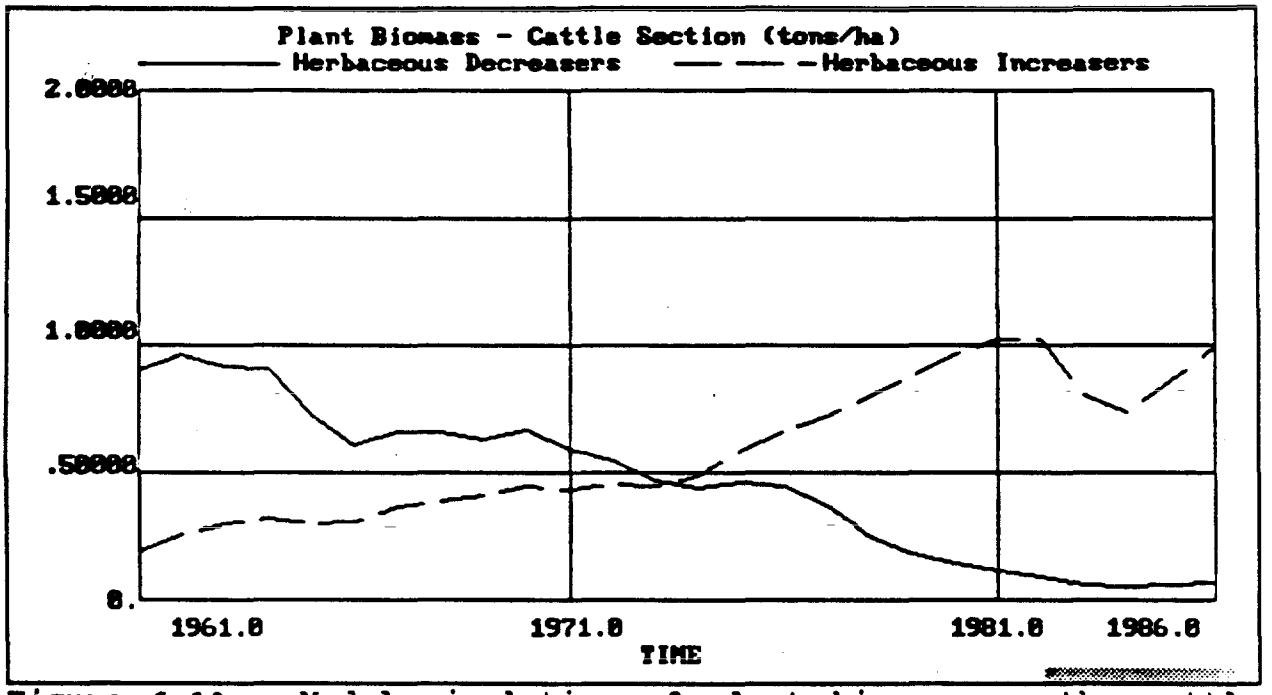


Figure 6-10. Model simulation of plant biomass on the cattle section of Buffalo Range. Overgrazing caused a shift in the grass species from perennials (decreasers) to annuals (increasers).

The very selective use of the available forage by cattle, as well as overstocking, reduced range productivity on the cattle section. In comparison, the game section fared much better (See

Figure 6-11). Instead of the shift in dominance characteristic of an overgrazed range, these results suggest maintenance of the status quo over the long term. The wild ungulate populations spread their forage consumption (See Figure 5-10) more evenly over the four plant categories, utilizing not only the grasses, but also the browse.

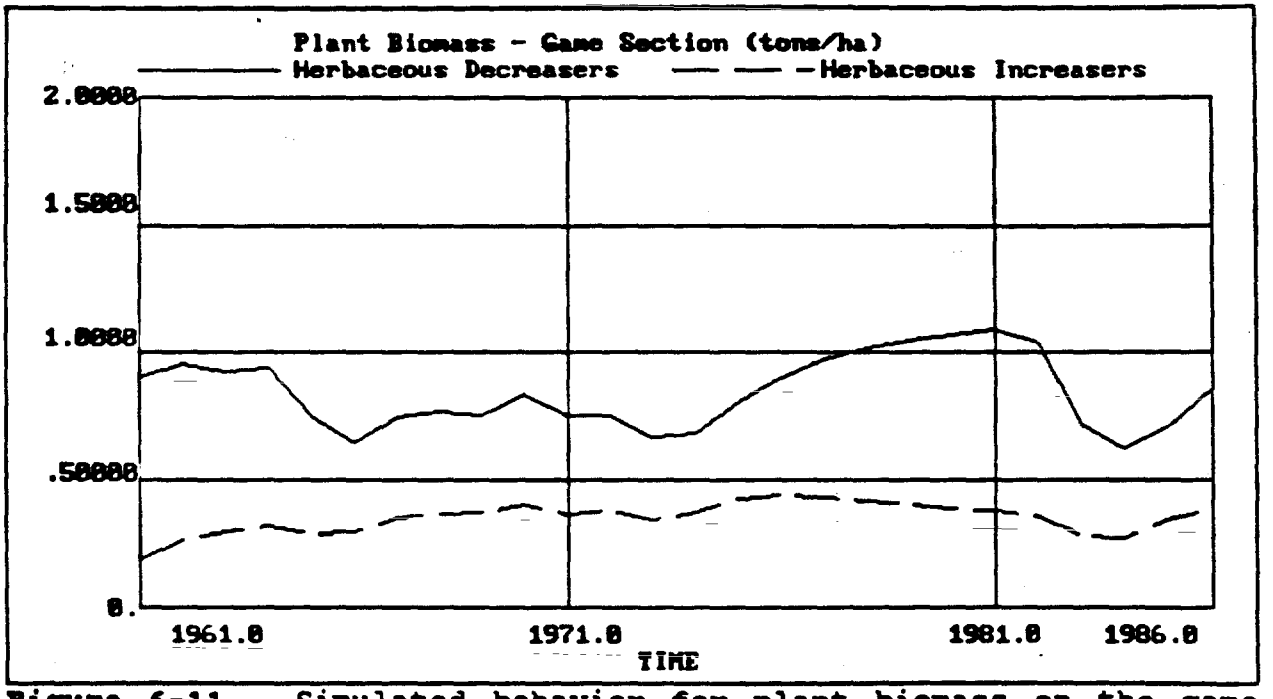


Figure 6-11. Simulated behavior for plant biomass on the game section of Buaffalo Range. The more diverse use of the forage by wild ungulates prevents overgrazing and range degradation.

Range condition on the cattle and game sections is compared by the model in Figure 6-12. The definition of range condition we use is relative to use by cattle and other grazers, and reflects the relative amounts of herbaceous decreasers to total

grass biomass. It does not include browse. A definition of range condition for browsing animals would include the relative amounts of browse available, which is absent from our definition. However, retrogressive change in herbaceous plants is generally a powerful measure of ecosystem health, reflecting, for example, the potential to capture water, minimize erosion, etc. (See Chapter 4).

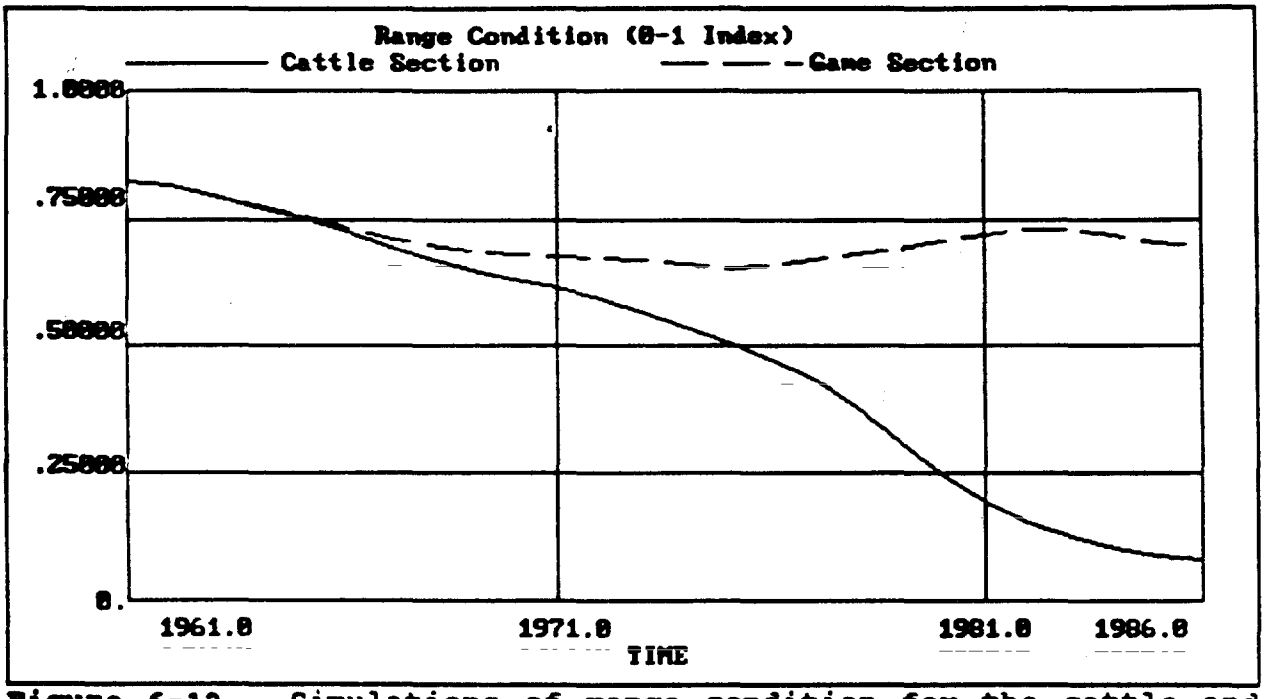


Figure 6-12. Simulations of range condition for the cattle and game sections. Range condition is defined as the relative amount of decreasers to the total grass biomass, a definition applicable for grazing animals.

Range condition on the cattle section declined steadily over the simulation period, reflecting the decline of decreasers as the percentage of increasers rose. Range condition on the game section remained fairly steady throughout.

Why did this occur? Section 5.3.3 and Figure 5-19 described the method used in the low veld of Zimbabwe to determine cattle stocking density. A set figure for stocking density is used, which is seldom if ever adjusted. This figure reflects the advice of extension agents (often three decades ago) and the rancher's perception of carrying capacity on his land. For this situation an actual stocking density of one livestock unit (455 kilograms of biomass, or one cow-calf unit) in 10 hectares was used. The model estimated the actual carrying capacity of grazers on the cattle and game sections of Buffalo Range (See Figure 6-13). On the cattle section, the actual carrying capacity (which is diagramed in the upper right of Figure 5-19) is estimated to be less than one in ten for all years except 1961-64. The carrying capacity estimates on the game section reflect its better condition and use.

The decline in immature cattle numbers is precipitated by range degradation, and enhanced by drought (See Figure 6-7). The combination of the two interacting effects precipitously reduces the cattle birth rate and thus herd size, not only for immature animals, but also for the other categories because replacement animals from the immature stock become more scarce.

What is the specific link between range degradation and reduced births? As we have seen, the use of a set figure to determine stocking density caused overgrazing and the eventual shift in dominance away from herbaceous decreasers to the

advantage of herbaceous increasers. This shift in palatability and nutritional value from one type of grass to another was followed by a decline in herd nutrition and reduced fertility. This decline began not during the awful drought years of the early 1980's, but during the exceptionally good rain years of the late 1970's (See Figure 6-14).

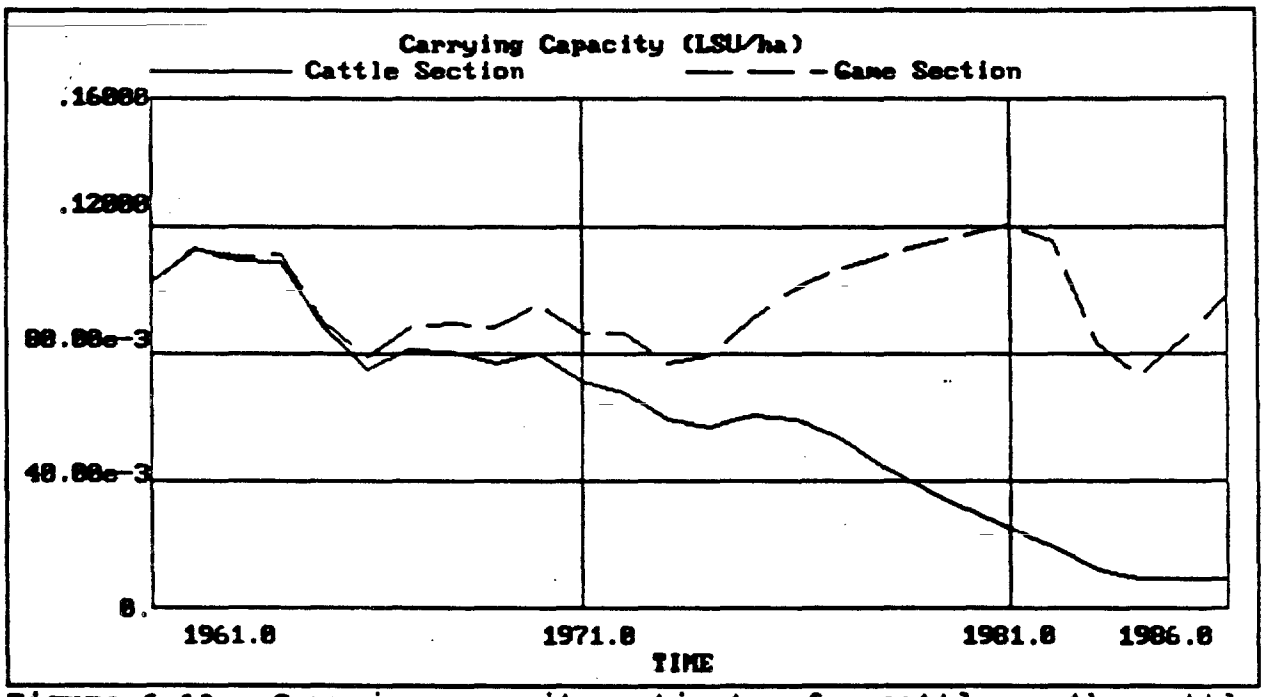


Figure 6-13. Carrying capacity estimates for cattle on the cattle and game sections. Carrying capacity is determined by forage availability, optimal consumption, and proper use, which declines as consumption increases.

The impact of these reductions on ranch income was severe. The decline in herd productivity reduced net income beginning in the middle of the good rains.

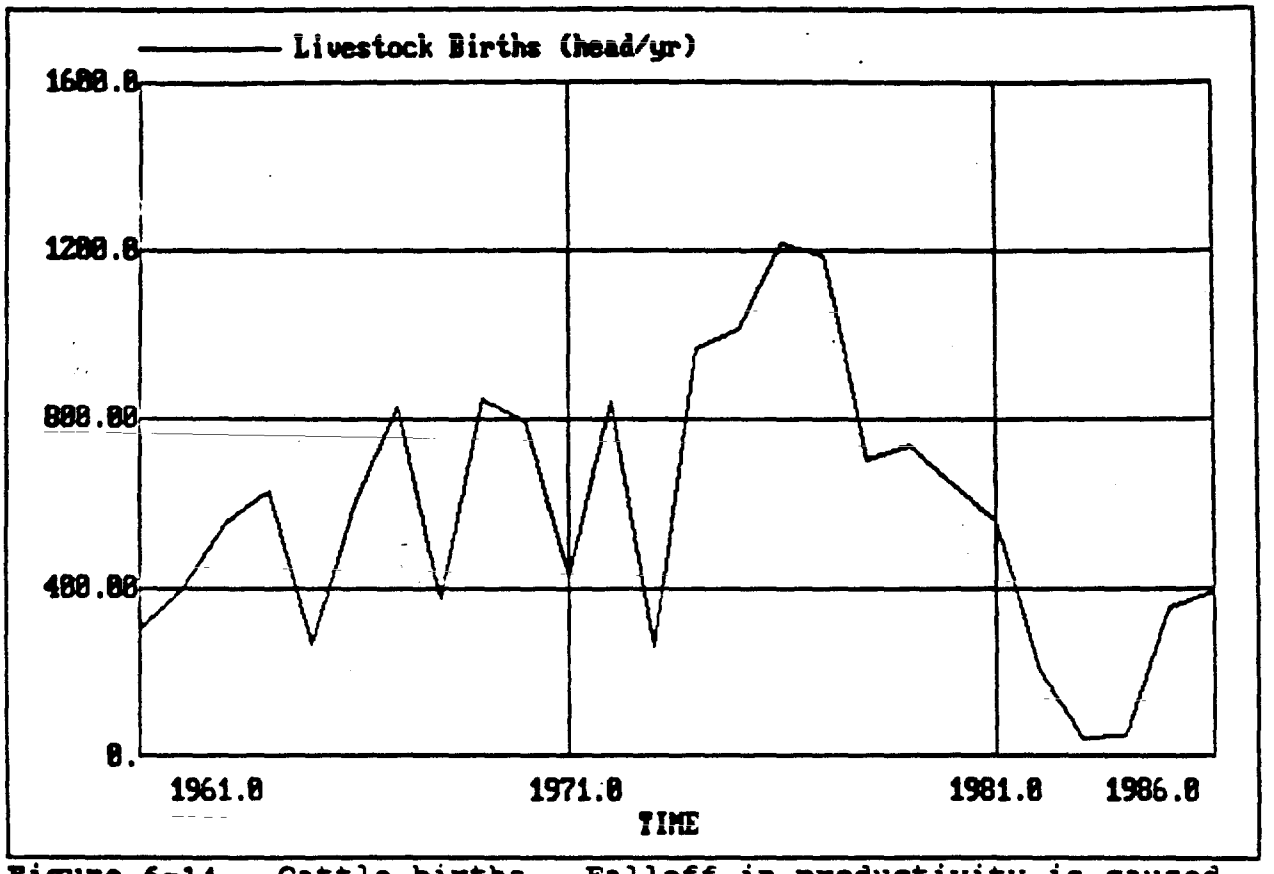


Figure 6-14. Cattle births. Falloff in productivity is caused by declining nutrition, a result of range degradation.

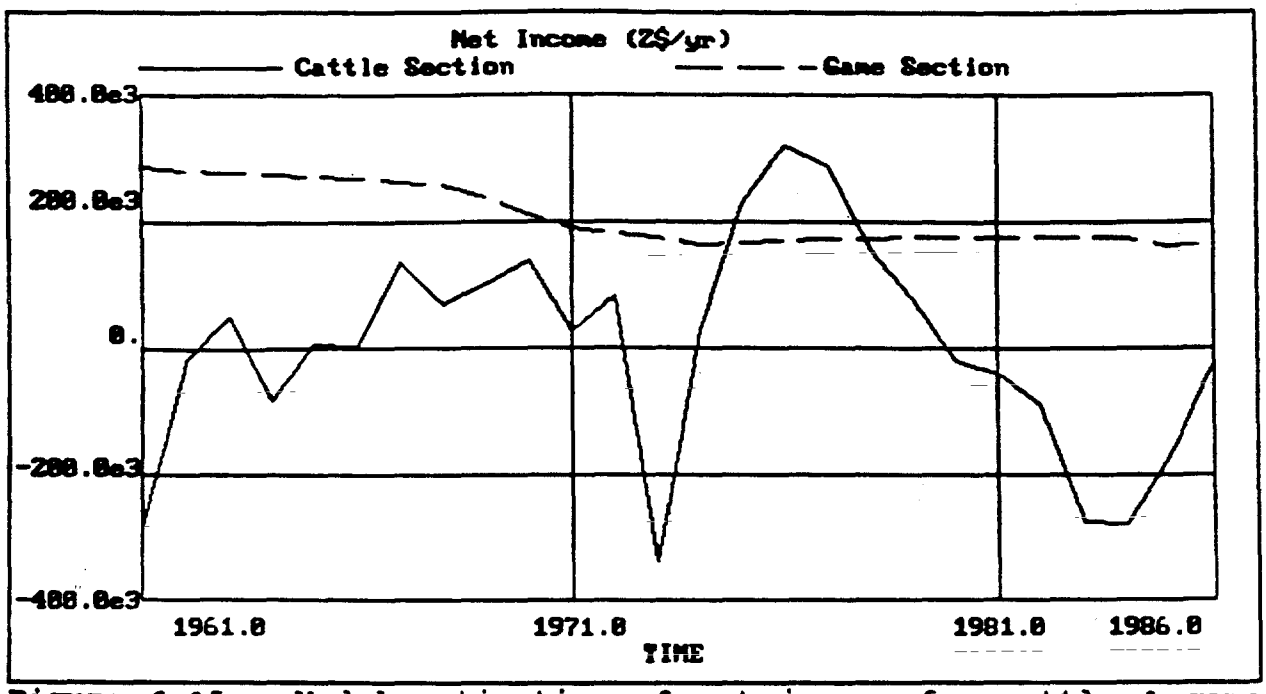


Figure 6-15. Model estimation of net income for cattle & game sections of Buffalo Range. Constant prices are assumed & derived from Child (1988). Incomes drops on the cattle section after 1976 as herd productivity falters.

When the births declined it did not take long for this reduced herd productivity to become apparent in the financial accounting of the ranch -- cattle shifted from profit to loss (See Figure 6-15). The behavior for cattle is generally like the shape of actual net income for the cattle operations, but since we have assumed constant prices the number differ significantly. The dip in 1972 is due to assumed costs of cattle purchases to accommodate the purchase of new land (See Figure 6-5). The net income for the game section is relatively stable and constant due to income from safaris. In fact, safaris only started in the early 1970's, but we have assumed a beginning in 1961 to facilitate comparisons.

6.4 Testing Management Options for Livestock Operations

Two problems frequently mentioned by commercial cattle ranchers in the low veld of Zimbabwe are declining range productivity and encroachment by brush. The decline of range productivity, and consequently the livestock herd, was explored in the previous section. The encroachment of woody plants appears to have been a relatively small player in the dynamics of the base case behavior. However, since brush was present in large quantities at least since 1961, and it significantly limits the amount of grass biomass through competition, it is an important constraint to range productivity for grazers (Chavunduka, 1985). The presence of bush is an indication of degradation for grazers.

We ran several tests with the model to look at the ecological and economic implications of management options to address these problems. This section presents and discusses these.

Surveying. The key element of proper range management is sound knowledge of the range resource. Ideally, this knowledge should be specific to the management area, and include information about the species present and their relative abundance, productivity and value. A ranch manager who has access to this type of information can assess the proper stocking density much more accurately than a rancher using a "thumbsuck."

The only accurate way to determine the information necessary for proper stocking is to conduct an annual survey of the ranch or area under management. These surveys are usually done at the beginning of the dry season, and livestock densities are set for that time to avoid overgrazing during this critical bottleneck period. Section 5.3 and Figure 5-19 outline the model structure for mimicking this management policy.

Burning. Grass productivity can be significantly increased by reducing competition from bush, particularly competition for light, because grasses will not grow in the shade of shrubs and trees (Chavunduka, 1985) or within the area influenced by heavy leaf fall or allelopathic elements (inhibiting chemicals). Burning is one of the more cost-effective means of clearing bush, but must be done carefully. A fire that gets out of control is dangerous to property, and destroys forage.

The best practice is to cut firebreaks and burn on a rotational cycle of perhaps twenty years. In this way only 5 percent of the forage is lost in any given year, and the fire can be controlled. Cutting and maintaining firebreaks is expensive. The analysis suggests though, that both burning and surveying the range are practices that could increase productivity enough, particularly in drought years, to pay for themselves.

Comparisons with the Base Case. We made three test runs with these assumptions:

- annual surveying of the ranch, and corresponding setting of stocking density using this information;
- burning on a twenty-year rotation, and
- both surveying and burning.

The results will also be compared to the base case as described in Sections 6.2 and 6.3.

Surveying the management area has a direct impact on the ranch manager's perception of the carrying capacity of the land. Figure 6-16 shows the model results for perceived carrying capacity for the base case, the run assuming annual surveying, and the run assuming both surveying and burning. The run for burning alone does not affect the perception of carrying capacity and is not included here.

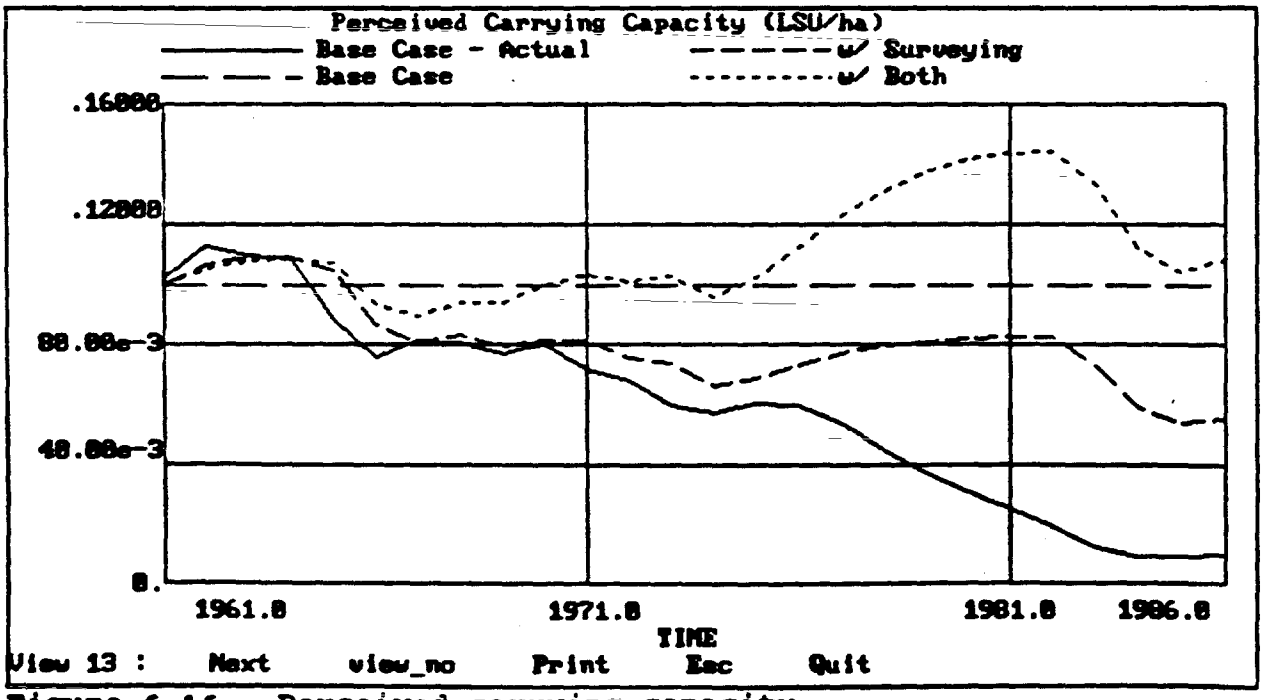


Figure 6-16. Perceived carrying capacity.

In the base case, the stocking density is set at 1 LSU in 10 hectares. Estimated actual carrying capacity is shown for the base case, as well as the perceived capacity for the case with surveying, and surveying and burning together.

In the base case the model assumes that the ranch manager sets the stocking density at one livestock unit (LSU) in 10 hectares and never changes it. The perceived carrying capacity is thus fixed at 1 in 10. The actual carrying capacity is quite a contrast -- the difference between the two is wide at the end of the simulation. The degradation of the range is so severe that actual carrying capacity falls to near one livestock unit in 100 hectares.

The reason for this dramatic divergence is the shift in dominance from decreasers to increasers (See Figure 6-11), which degrades the range and lowers proper use. These two factors determine the actual carrying capacity. Figure 6-12 illustrated the range condition for the base case. Proper forage use Figure 6-17) decreases as range condition declines, so that as the range deteriorates an increasingly smaller fraction of the available forage can (or should) be consumed.

In the relationship between range condition and the proper forage use fraction, 50 percent of the forage could be consumed for proper use at maximum range condition (for cattle) (See Figure 6-17). As range condition falls to zero, so to does the proper forage use fraction, so that even though some forage may be available, proper use would dictate that the range be rested.

The perceived carrying capacity more accurately reflects the actual carrying capacity when the range is surveyed on a regular basis. The model assumes that the perceived carrying capacity follows the actual carrying capacity with a lag of one year, so that they are essentially the same, relative to base case results. Figure 6-16 shows that perceived carrying capacity with surveying, and with both surveying and burning, is dramatically different than the actual carrying capacity in the base case.

At maximum range condition (for grazers), proper range use dictates that up to 50 percent of the forage could be consumed. This fraction of proper forage use declines with range condition.

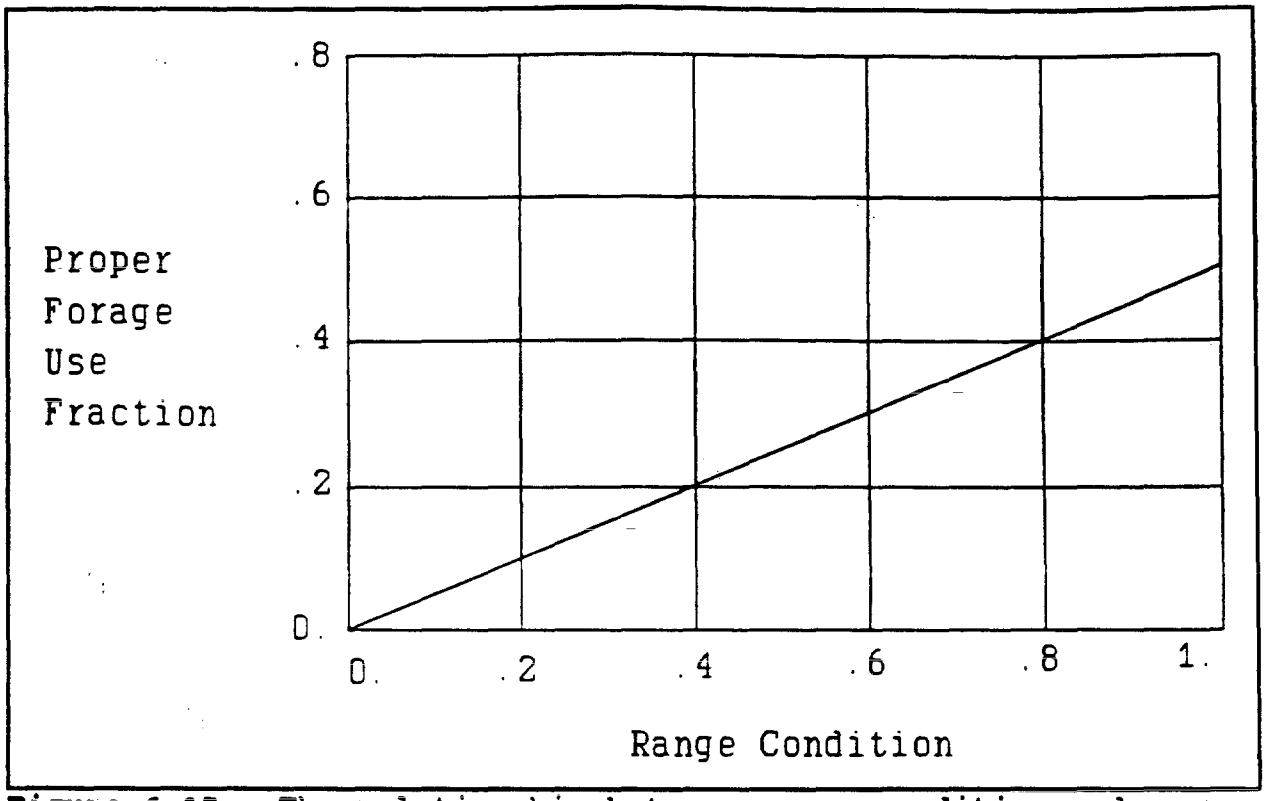


Figure 6-17. The relationship between range condition and proper forage use fraction. Range condition is a 0-1 Index.

For the case with surveying alone the improved carrying capacity is the result of proper range use, while for the case with both surveying and burning the results are a combination of proper use and range reclamation.

For both categories of brush -- shrubs and saplings, and large woody plants -- burning controls or reduces the abundance of brush relative to the base case (See Figures 6-17 and 6-18). The reduction of bush lowers competition for the grasses, so they improve along with the range condition (See Figure 6-19).

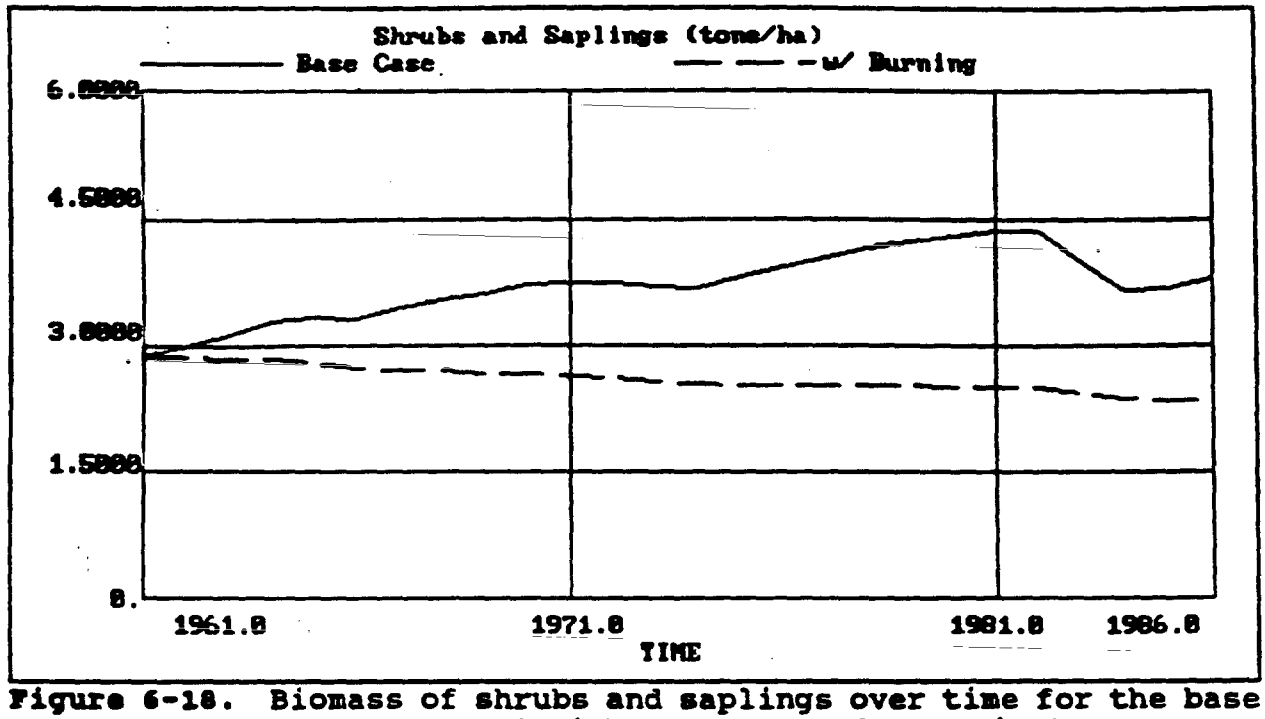


Figure 6-18. Biomass of shrubs and saplings over time for the base case (no bush control), and with bush control (burning).

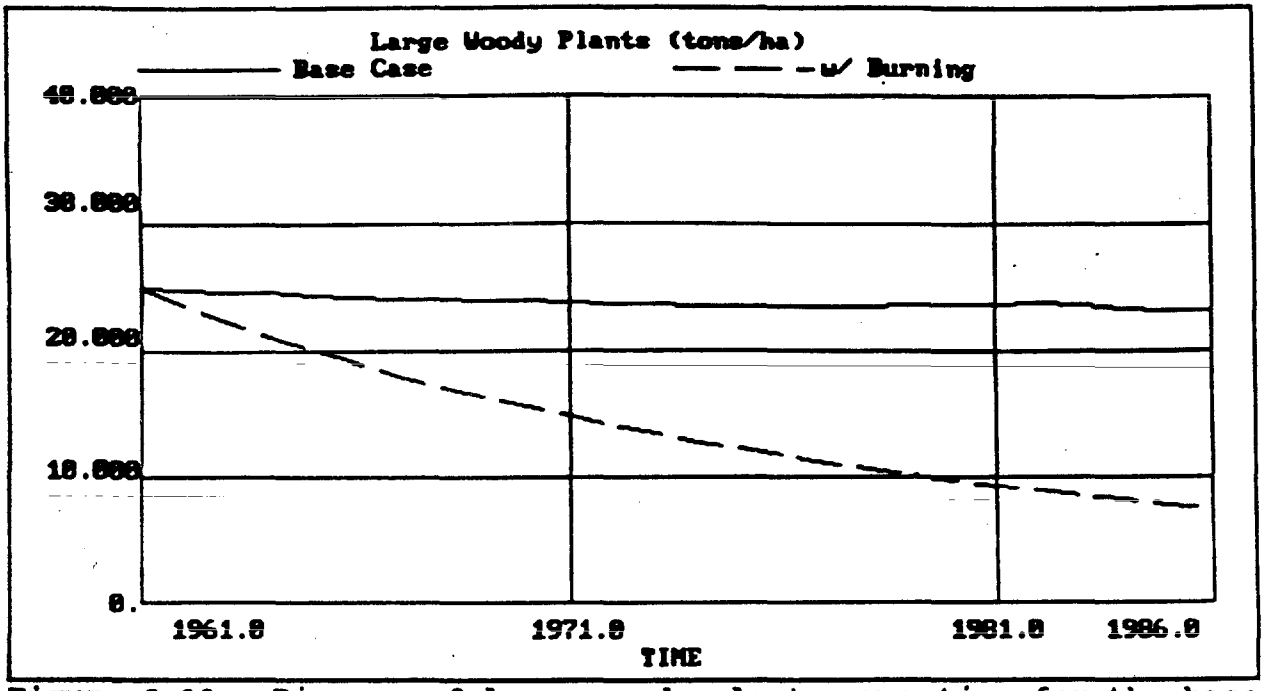


Figure 6-19. Biomass of large woody plants over time for the base case and with burning.

Fairly severe overgrazing in the base case seriously degrades the range, but some degradation occurs even with surveying and proper use (See Figure 6-20). This degradation is caused by the selective nature of forage consumption, and is the inevitable consequence of stocking a single species, cattle, which prefer grasses in general and herbaceous decreasers in particular.

Recall Figure 6-12, which showed range condition on both the cattle and game sections for the base case. Range condition was preserved on the game section without burning or surveying, simply because forage consumption was more diverse and less focused on the grasses.

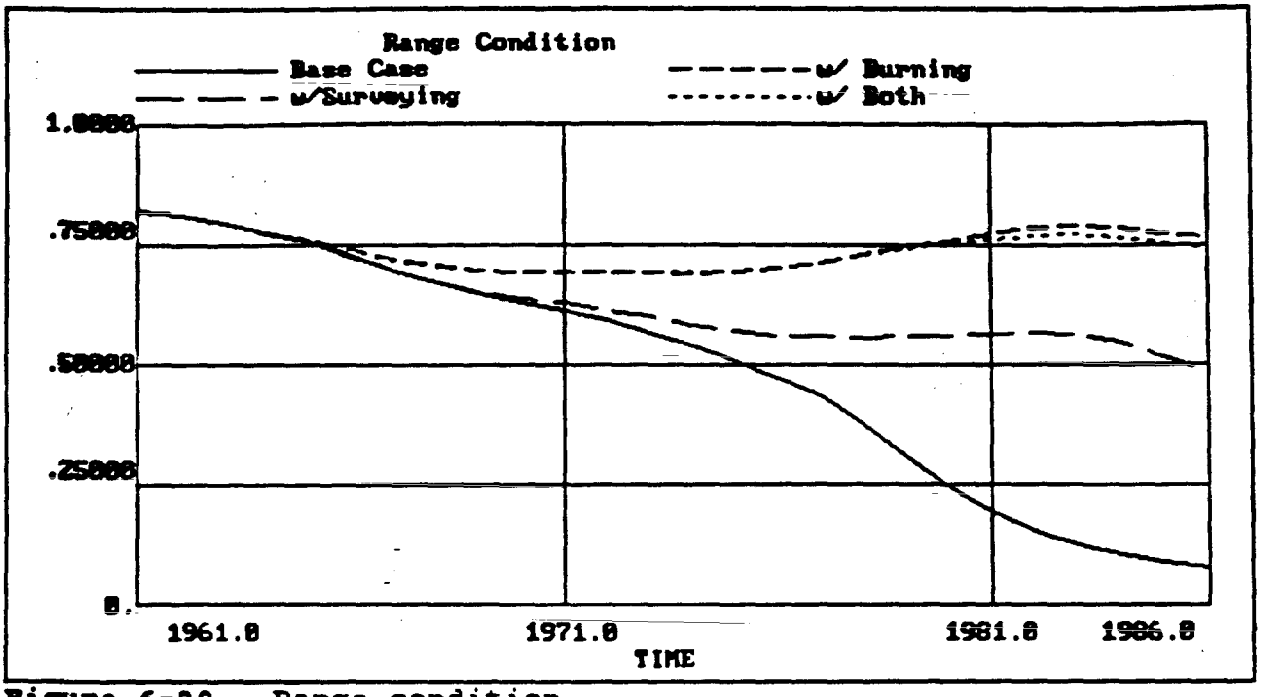


Figure 6-20. Range condition.

A severe decline in range condition is experienced in the base case. Surveying helps to ease this degradation and burning maintains a good range condition.

Figures 6-21, 6-22, and 6-23 show model results for the cattle herds for the base case, surveying, burning, and both surveying and burning. In all cases the herd sizes for immature cattle, mature female cattle, and mature male cattle are fairly similar for all runs until the good rains start in 1973, when the tests diverge (See Figure 6-4).

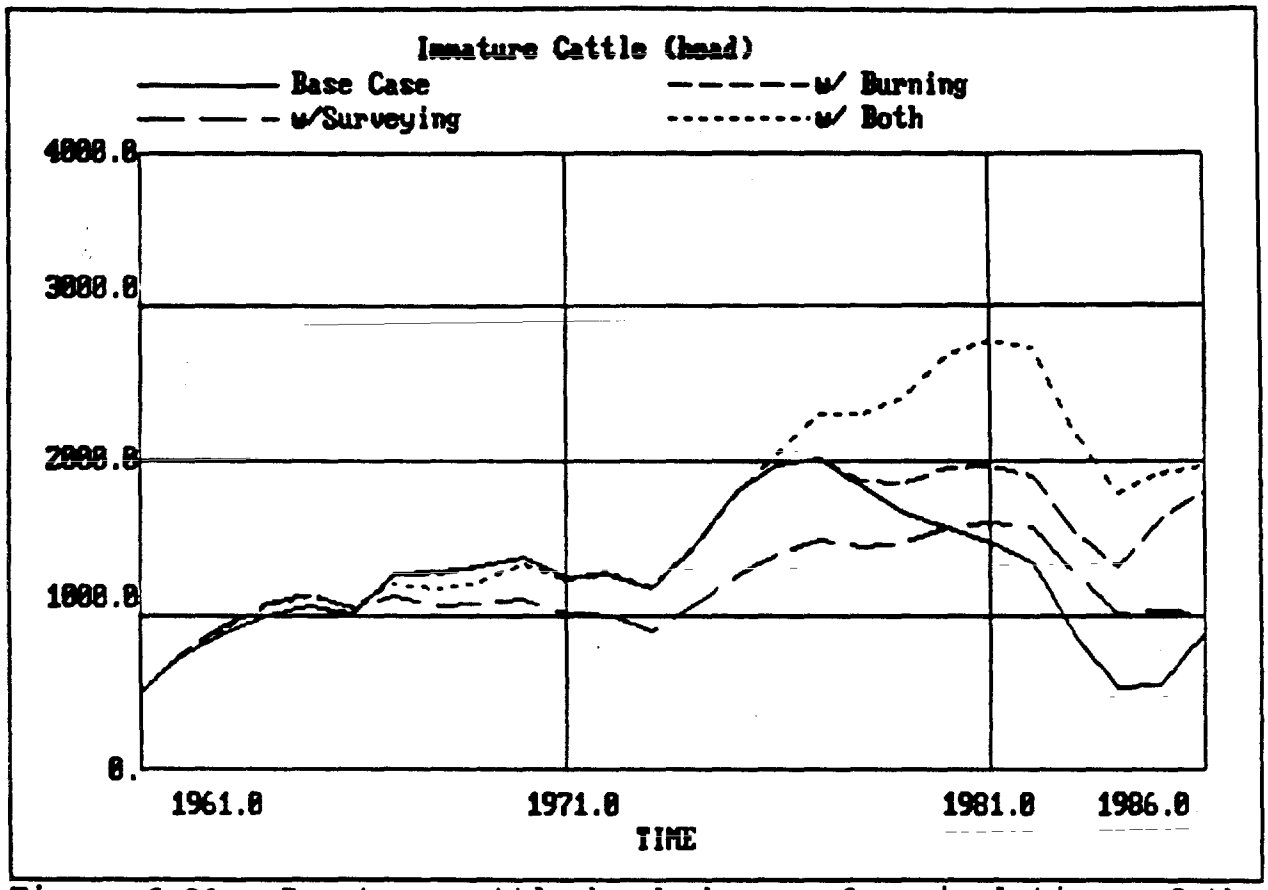


Figure 6-21. Immature cattle herd changes for simulations of the base case, with surveying, with burning, and with both surveying and burning.

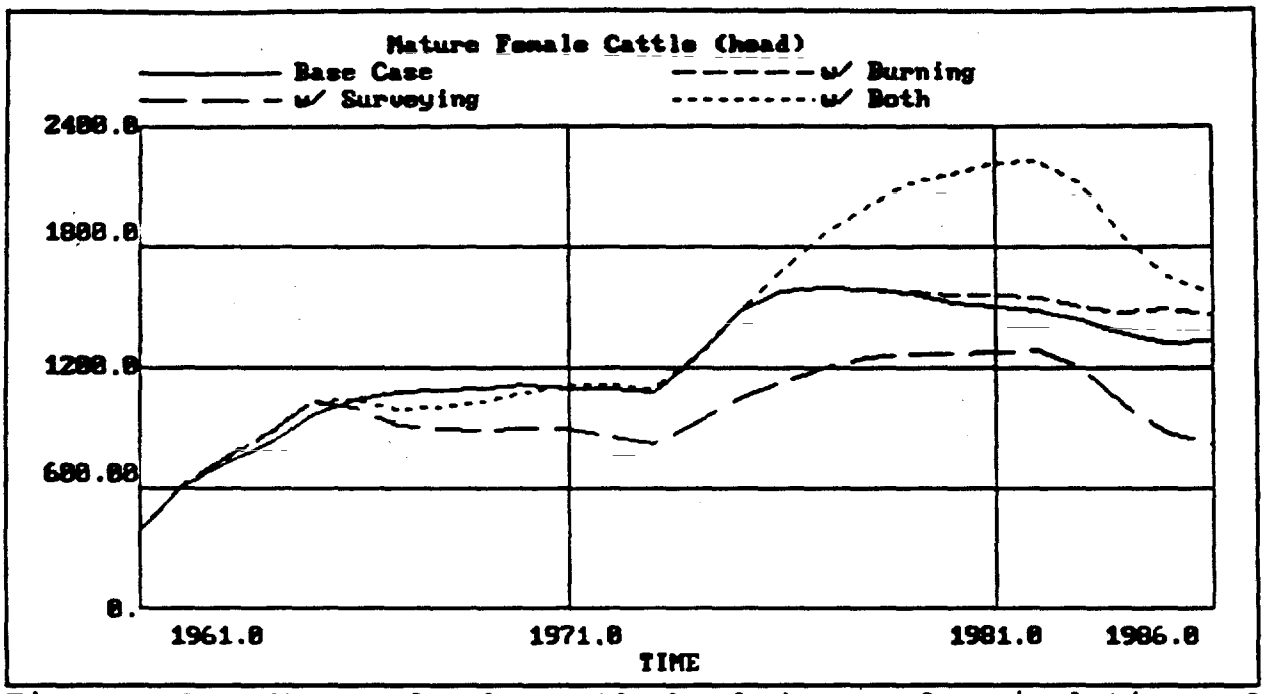


Figure 6-22. Mature female cattle herd changes for simulations of the base case, with surveying, with burning, and with both surveying and burning.

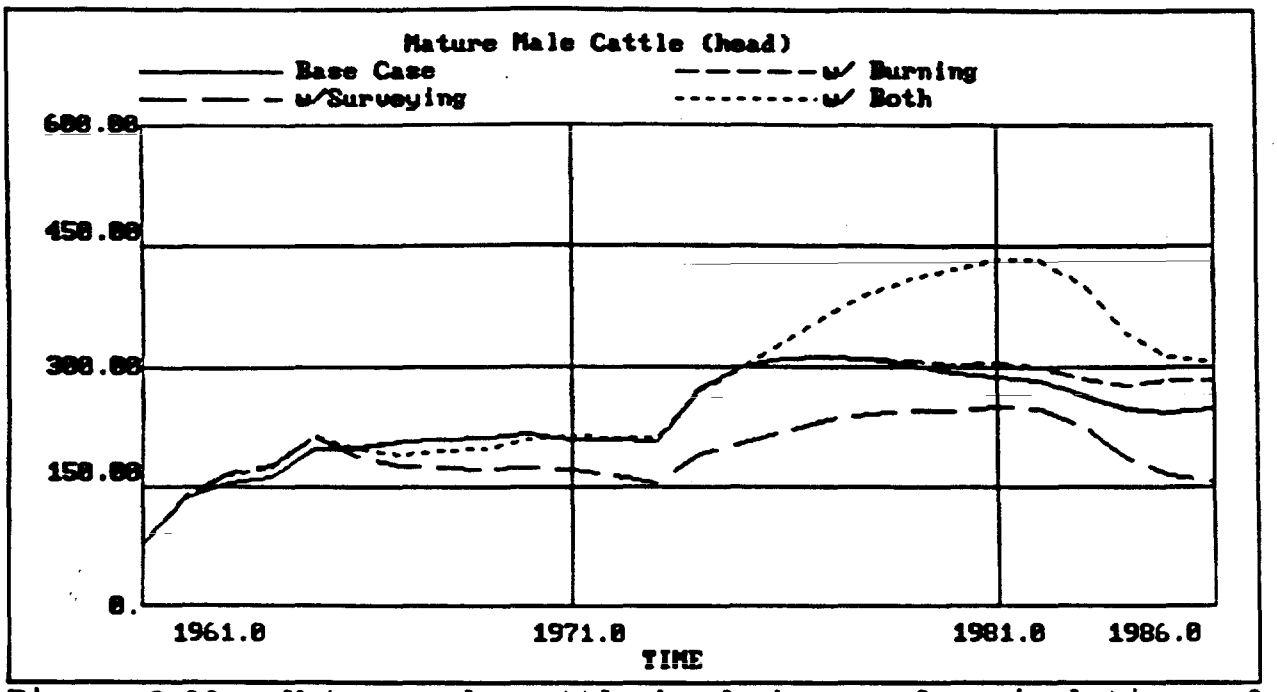


Figure 6-23. Mature male cattle herd changes for simulations of the base case, with surveying, with burning, and with both surveying and burning.

The results for the immature cattle herd showed the most marked differences of the four simulations. In the base case the herd size began to decline in the middle of the good rain years as a result of declining range condition and nutrition. With surveying, the herd size was smaller until 1979, reflecting the actual carrying capacity and proper stocking rates, and experienced a much less dramatic decline during the drought because the range was in better condition when the drought occurred.

When a policy of bush control for range reclamation was implemented, excluding a change in the method of stocking, the simple method of setting the stocking rate was no longer a

constraint. The actual carrying capacity was always above the perceived carrying capacity, except during the drought. Thus the herd numbers were maintained, while in the base case, they dropped.

Finally, with the combination of surveying and burning, a synergy of the two policies was evident. Not only did the range condition improve relative to the base case due to the bush control, but with the use of surveying, the ranch manager was in a position to take advantage of the good rains and range improvement, and set the herd size at higher levels without damaging the range. The mature female and male herds showed similar, but less pronounced results for these tests.

The results of the management options tested here suggest that these policies could have not only profound beneficial effects upon the ecological health of the ranch, but also upon its financial state.

Declining quality of the range as reflected by condition implied reduced primary as well as secondary production. This decline in cattle productivity was reflected in the balance sheet of the ranch (See Figure 6-24). Improved range productivity from using better methods of setting stocking rates and from range reclamation was also seen.

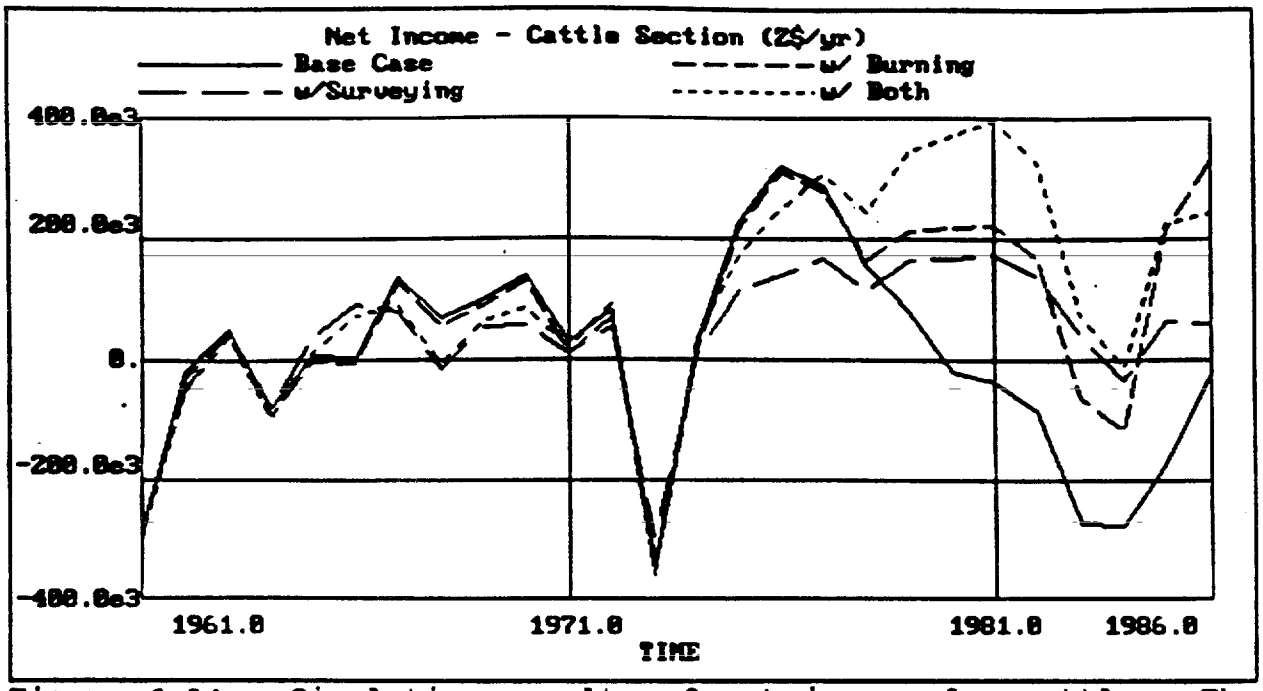


Figure 6-24. Simulation results of net income for cattle. The base case is compared with tests of surveying, burning, and surveying and burning.

For the base case, net income declined and showed severe losses when the herd size fell and revenues were lost. Recall that net income was also negative when the ranch size increased in 1973 and cattle purchases were required.

Each of the policies tested showed a significantly better result for net income than the base case. When surveying was implemented, net income was lower until the herd size began its decline in 1978. The use of surveying and proper stocking allowed a lower, but still positive, net income to be maintained until the drought. During the drought the losses were much less severe, and net income was not so strongly negative.

When a policy of burning without surveying was applied, net incomes were even higher, and there was only one year of minor losses during the drought.

The combination of surveying and burning showed a net income which was very different from the base case in the latter half of the simulation. The gap in net income between this test and the base case was quite dramatic. These runs suggest that sound ecological management of the range can pay very handsomely, which is confirmed by net present values analysis (See Figure 6-25).

For each of the three management options, net present values were calculated assuming a 12 percent discount factor (the interest rate) for both costs and benefits. Costs were assumed to be Z$2,500 (Zimbabwe dollars) per year for the surveying (roughly Z$0.10 per hectare) and Z$0.45 per hectare per year for the burning program. Recall that about 5 percent of the ranch would be burned each year under the assumptions used here. The two policies together would cost Z$12,500, or Z$0.55 per hectare per year.

The benefits of the programs were assumed to be the differences between the net income for the base case, and the net income for each of the tests. These benefits, as well as the costs, were discounted to reflect their present value in 1961. Annual results for the net present values were calculated as if the investment program ended in the given year. Thus, if the burning program ended in 1971, that investment would have shown a

negative net present value -- the investment would not have paid for itself. If evaluated after 1981 however, the results showed a very strong positive payback. This illustrates the earlier point that range programs require long-term planning and investment.

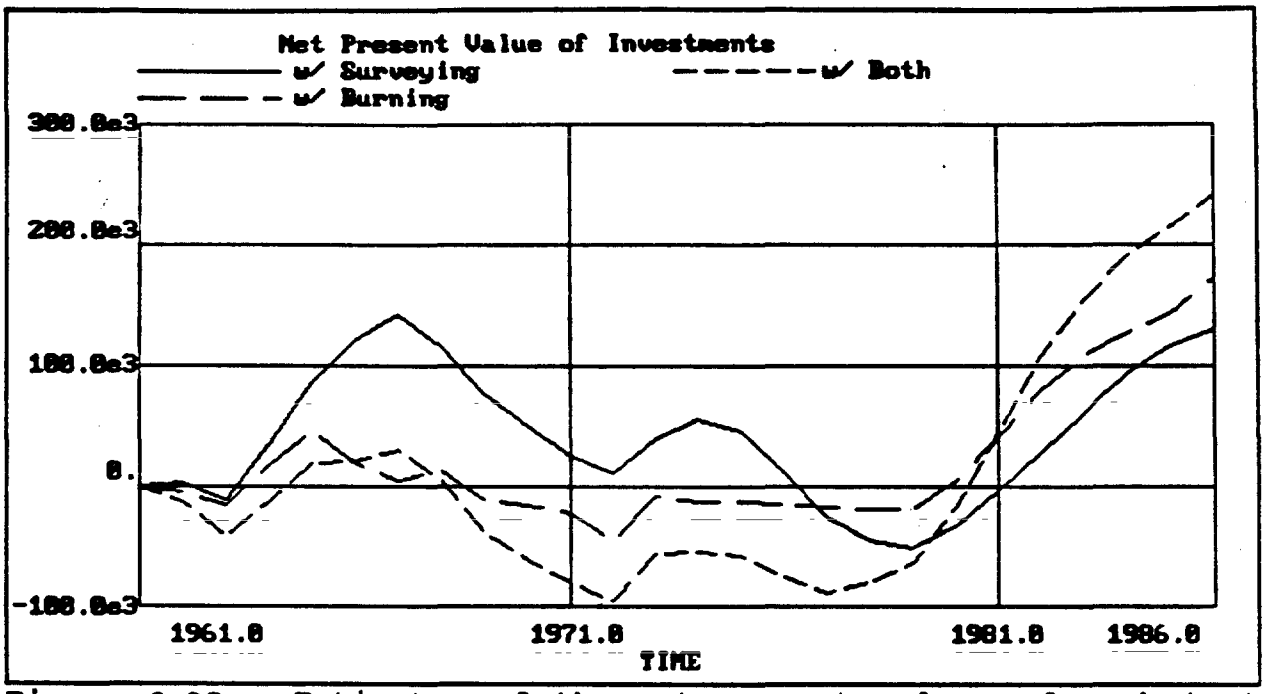


Figure 6-25. Estimates of the net present values of each test case: surveying, burning, and both together.

The investments in burning and surveying paid off extraordinarily well as measures to protect and sustain the productivity of the range resource under cattle ranching. Their value became obvious during drought periods when range productivity would decrease and become unsustainable under existing stocking pressure.

There must be, of course, some limit to the expenses of range improvement and reclamation programs. What are these values? To determine a rough estimate of the maximum economic investment, we ran the model to find the break-even point for the surveying and burning programs at the end of the simulation. This break-even point occurs when the investment has yielded enough benefits to just pay for itself, that is, when the net present value is zero (See Figure 6-26). We assumed the same discount factor of 12 percent. The break-even cost for the surveying program was about Z$9,500 per year, or a little less than Z$0.45 per hectare per year. An investment in burning could be about double the surveying program, because the break-even investment level was about Z$19,000 per year, or approximately Z$0.85 per hectare per year. These per hectare costs for burning were figured using the entire ranch size, not just that 5 percent that was burned each year.

These results depend on several key assumptions, including the discount factor. A higher discount factor would indicate lower break-even investments, while a lower discount factor would raise the break-even point.

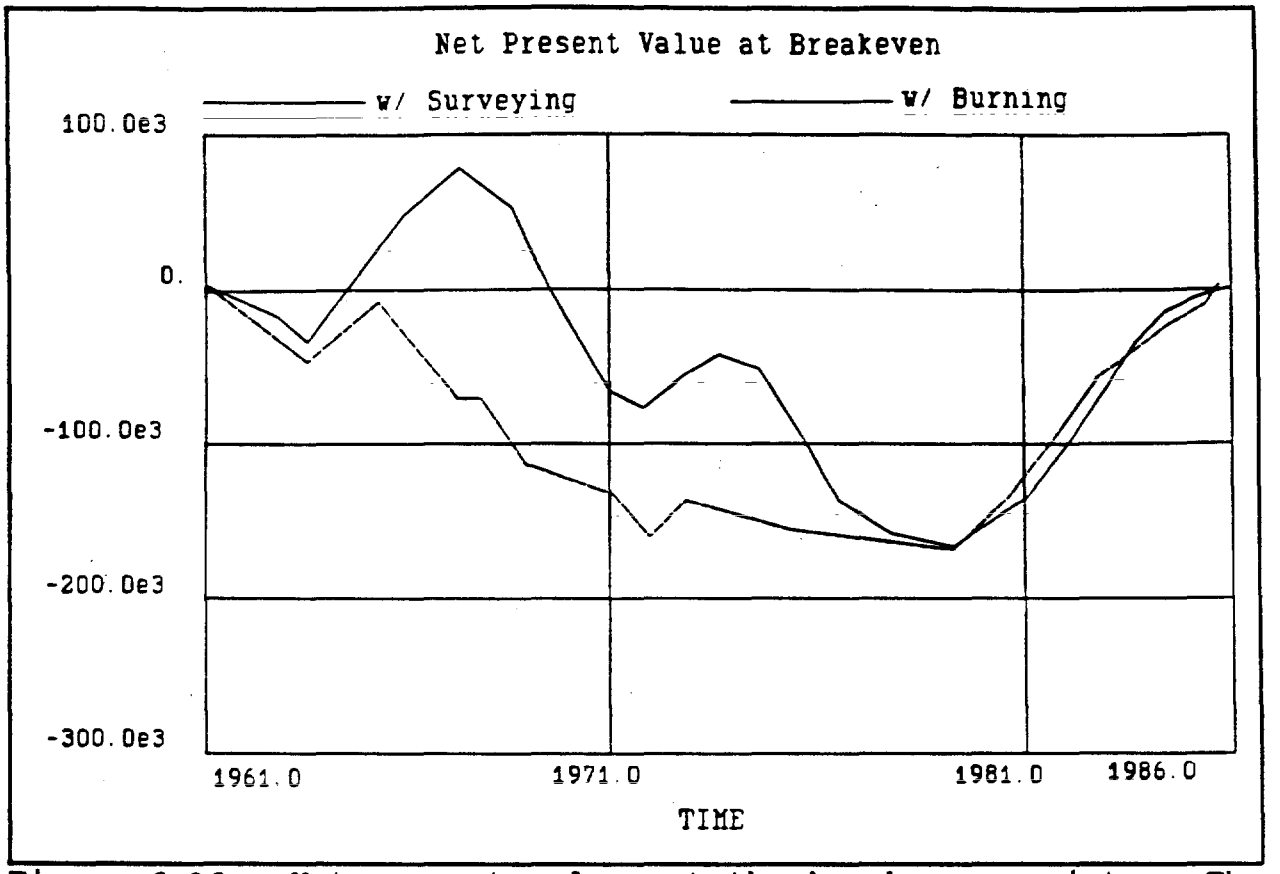


Figure 6-26. Net present values at the break-even points. The break-even point is achieved at the last year of the simulation, 1986.

6.5 Parametrical Sensitivity Analysis

Analysis of the sensitivity of model results to the parameters used is important to better understand the model behavior, as well as the behavior of the actual system.

Sensitivity analysis is a rather tedious process conducted throughout the building and evaluation of a simulation model. There are two broad types of sensitivity analysis: structural and parametrical. Structural sensitivity is analyzed at each step when the model is tested to see which parts of the explicit

structure (the equations) are most important in determining results. The parts of the model structure that are more important can be expanded upon, while those that are less important can be collapsed, even to the point of implicit representation by parameters (initial values, constants, and tables), or elimination. The final model structure is a result of considerable analysis of this type.

Model parameters are also analyzed throughout the model construction and calibration efforts. When the model has been completed and validated, a standard parametrical analysis can determine how a given change in a parameter affects the outcome. These results can then be judged against the base run, and one against the other to get a more objective notion of model sensitivity. By relating these back to the model structure and to the real system, priorities for research and data collection can begin to be set.

An important concept in sensitivity analysis is the need to clearly specify which aspects of model behavior are to be examined. Some changes in parameters will produce only small local changes, while others may have very large, widespread ramifications. The sensitivity of a change in a given parameter can only be gauged in the context of a specific result.

In the larger context of setting research and data collection priorities, it must also be remembered that there are limits to generalizing the results from the analysis of

sensitivity to parameters, because the results depend to somewhat on all the other parameters in addition to the one being tested. This generalization can be guided to a certain degree by the sensitivity analysis itself.

For the results reported here, we first went back to the results of the Chiredzi workshop to determine the context for testing and analyzing the parameters. We were most interested in testing the parameters of the model to see how they affect the goals as identified by the participants of the workshop.

Two of the most important goals listed were to "make money," and to "maintain [the] ecological productivity and/or improve it." (See Section 5.2.2) These two goals are captured by the model in the range condition and net income variables, respectively. These are goal variables.

Because of the time and effort that would be required to evaluate every parameter in the model (which would require almost 400 simulations), some method must be used to reduce this to a manageable task. For each of the goal variables we work backwards through the model structure to identify parameters. There are many feedback loops and links to other parts of the model. The appropriate initial value, constant, or table which acts as the link to the other parts of the model was identified. A list of these parameters and the linkages was compiled.

With this initial list, simulations were run, changing each of the values by a given amount, in this case 10 percent. Two runs were made -- increasing and decreasing the parameter by 10 percent. These runs were then compared against the base case result for the goal variable being considered. Those runs which showed little or no change from the base case were eliminated from further consideration. Those parametric changes which showed considerable change were explored further. Figures 6-27 and 6-28 show the range of results from greatest positive to greatest negative change from the base case for both goal variables.

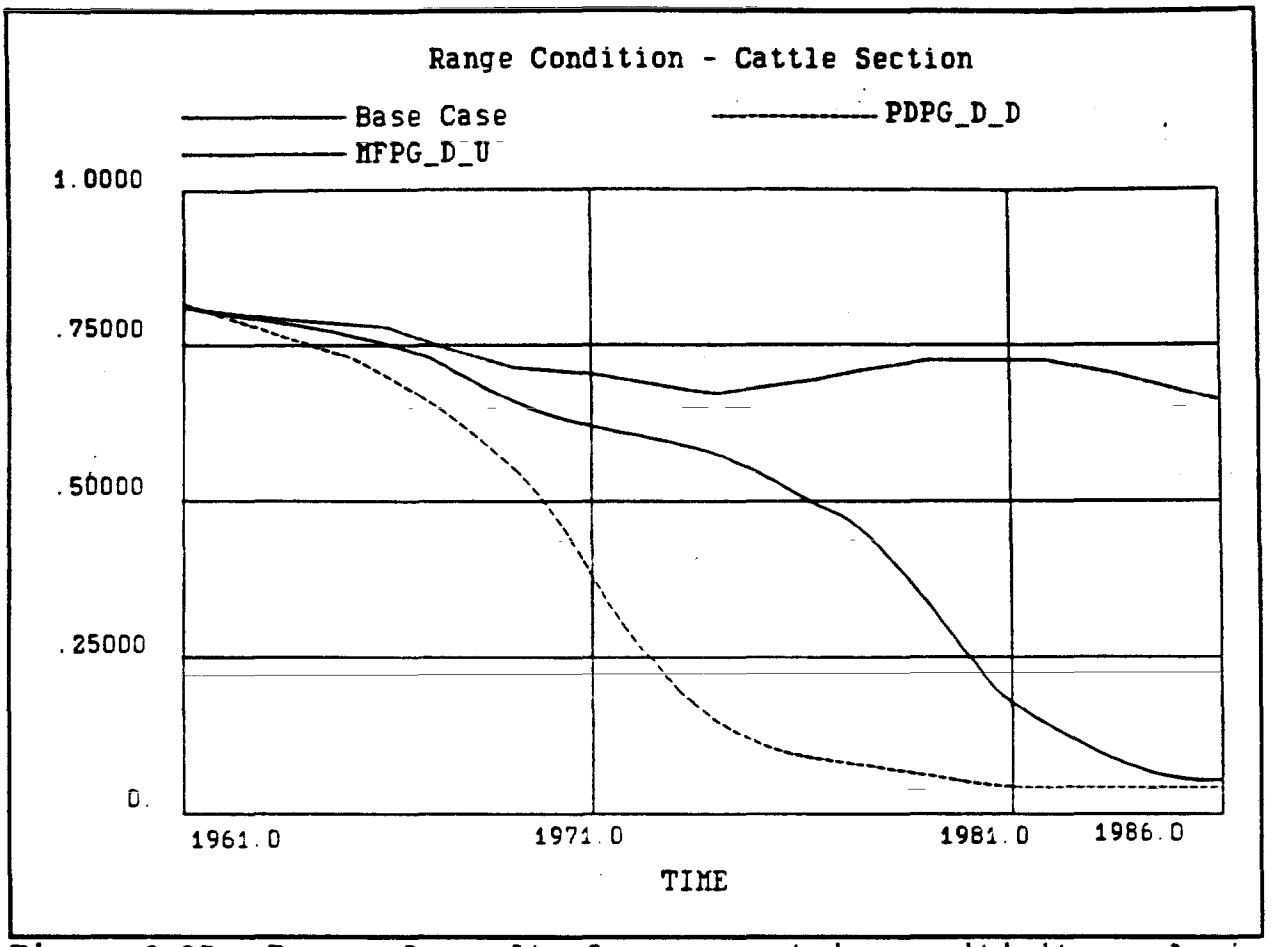


Figure 6-27. Range of results from parametric sensitivity analysis for range condition.

The base case is compared with parameter changes representing an increase in the maximum fractional plant growth for herbaceous decreasers (mfpg_d_u), and a decrease in the growth of herbaceous decreasers as plant density increases (pdps_d_d). [In the nomenclature used here the acronym for the variable is followed by the plant category _d= decreaser -- and a "d" for a decrease in value (down) or a "u" for an increase in value (up).]

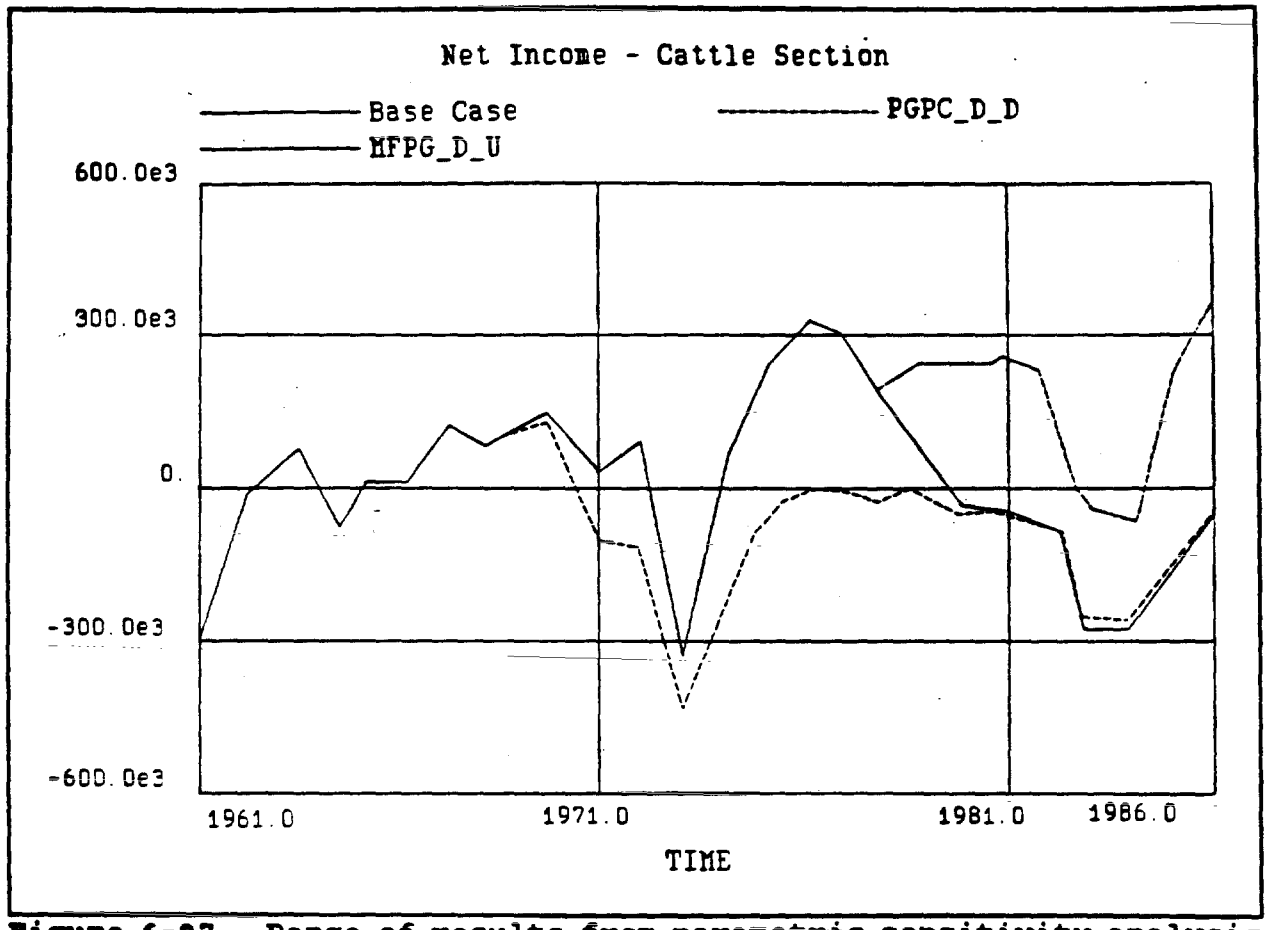


Figure 6-27. Range of results from parametric sensitivity analysis for net income.

The base case is compared with parameter changes representing an increase in the maximum fractional plant growth for herbaceous decreasers (mfpg), and an decrease in the growth of herbaceous decreasers as plant density increases (pdps_d_d). [In the nomenclature used here the acronym for the variable is followed by the plant category _d= decreaser -- and a "d" for a decrease in value (down) or a "u" for an increase in value (up).]

These runs showed the extremes of model behavior possible with a 10 percent change in any given parameter for this situation. It is important to note that a combination of changes could result in a synergy that produces greater differences from the base case.

When the model simulations were completed, the numerical results were loaded into a spread sheet for further analysis and ranking. We chose a fairly simple method of ranking, first calculating the area under each curve for the goal variables, then determining the absolute difference of this area from the base case for each run. The runs can then be ordered accordingly. Tables 6-1 and 6-2 show the results of the parametric sensitivity analysis.

Table 6-1. Results of parametric sensitivity analysis for range condition.

Parameter	Change*/ Type**	Area	Difference in area	Percent change
Base Case	NA	12.78		0.0
Maximum Fractional Plant Growth (Herbaceous Decreasers)	Inc/C*	18.66		46.0
Effect of Plant Density on Plant Growth (Herbaceous Decreasers)	Inc/T	18.59		45.5
Maximum Grass Biomass	Inc/C	17.81		39.4
Viable Seed Stock (Herbaceous Increasers)	Dec/C	17.12		34.0
Initial Plant Biomass (Large Woody Plants)	Dec/I	17.02		33.2
Effect of Plant Density on Plant Growth (Herbaceous Increasers)	Dec/T	16.89		32.2
Normal Fractional Litter Fall (Herbaceous Decreasers)	Dec/C	16.82		31.6
Effect of Soil Moisture on Maximum Grass Biomass	Inc/T	16.8		31.5
Biomass Accumulated from Seed Growth	Dec/C	16.69		30.6
Effect of Herbaceous Decreasers Density on Increaser Growth	Dec/T	16.61		30.0
Effect of Plant Density on Plant Growth (Herbaceous Decreasers)	Dec/T	8.98		29.7
Maximum Fractional Plant Growth (Herbaceous Decreasers)	Dec/C	8.98		29.7
Burning	NA	19.34		51.3
Surveying & Burning	NA	19.24		50.5

*Inc = increase, Dec = decrease. **I=initial value, C=constant, T=table.

Table 6-2. Results for parametric analysis for net income.

Parameter	Change*/ Type**[1]	Area (net income, Z$ x 26 years)	Difference in area (Z$x 26 yrs)	Percent change
Base Case	NA	107,836		0
Maximum Grass Biomass	Inc/C	2,243,934		1,980
Effect of Plant Density on Plant Growth (Herbaceous Decreasers)	Inc/T	2,212,448		1,951
Maximum Fractional Plant Growth (Herbaceous Decreasers)	Inc/C	2,209,916		1,949
Effect of Soil Moisture on Plant Growth (Herbaceous Decreasers)	Inc/T	2,061,301		1,811
Initial Plant Biomass (Large Woody Plants)	Dec/I	2,043,995		1,795
Effect of Plant Density on Plant Growth (Herbaceous Decreasers)	Dec/T	-1,800,140		1,769
Maximum Fractional Plant Growth (Herbaceous Decreasers)	Dec/C	-1,799,066		1,768
Maximum Fractional Plant Growth (Herbaceous Increasers)	Dec/C	1,998,327		1,753
Effect of Plant Density on Plant Growth (Herbaceous Increasers)	Dec/C	1,958,336		1,716
Normal Fractional Litter Litter Fall (Herbaceous Decreasers)	Dec/C	1,957,327		1,715
Viable Seed Stock (Herbaceous Increasers)	Dec/C	1,956,600		1,714
Surveying & Burning	NA	2,659,280		2,366
Burning	NA	1,918,669		1,679
Surveying	NA	1,031,574		856

*Inc = increase, Dec = decrease. **I = initial value, C = constant, T=table.

Several comments should be made to aid in the interpretation of Tables 6-1 and 6-2. First, in the "Change/Type" column, we indicate whether the value of the parameter increased or decreased, and the type of parameter, whether an initial value, a constant, or a tabular relationship. For a table, which has multiple values, all the values in the table are changed unless definitionally determined. For example, if a neutral effect is indicated by the number one, this value is not changed.

Second, for the parameters in the first column labeled "Effect of . . .", an increase in the values might suggest an increase in the effect. In fact the opposite is true. The values for "effects" range from zero (maximum effect) to one, (no effect). Mathematically, this is explained because any number multiplied by zero is zero, while any number multiplied by one is the same number. Therefore, an increase in the values for "effects" away from zero and toward one decreases the impact of the "effect" on the model results even though the parametric values have been increased.

For example, Table 6-1 includes the parameter "Effect of Plant Density on Plant Growth (Herbaceous Decreasers)". The values for this table have increased, but the results show a very significant improvement in range condition from the base case (the area under the curve is greater by 32.2 percent). By increasing the values of the table toward one, the density of

plants on the growth of herbaceous decreasers is diminished -- the growth of the decreasers does not slow as much due to competition from other plants, and so range condition is improved.

Unlike the analyses presented in the previous sections of this chapter, the results of the parametric analysis do not necessarily have a direct bearing on policy choices for natural resource management. This is true because some of the parameters of the system as shown here are beyond the control and influence of the ranch manager. However, knowledge of the system characteristics will lead to a more informed policy or management decision.

The results are very useful to help set research priorities. The reader will notice that all of the most sensitive parameters for both analyses relate in some way to plant growth. One might have expected, particularly for the net income analysis, that prices would have shown up somewhere. In the context of the whole system though, the health of the supporting resource system, the range, and therefore the productivity of the secondary system, livestock, turns out to be much more important than prices received or paid. A 10 percent change in growth factors influences the outcome to a much larger degree than the same change in economic factors. A favorable economic environment can not overcome a bad ecological environment.

The two tables also include comparisons with policy runs. For the analyses of both range condition and net income sensitivity, the greatest overall change, as well as the greatest positive changes, came from the burning policy for range condition, and surveying and burning together for net income.

6.6 Conclusion

The primary policy conclusion for range management in Africa to be drawn from this analysis is that there are options available which are both ecologically and economically sound. Several fairly simple, inexpensive, and workable alternatives were demonstrated to change the behavior of a collapsing and unprofitable system into a sustainable and profitable one. Additionally, game ranching was demonstrated to have considerable potential for the ranch economy, while maintaining ecological soundness.

The Integrated Planning Technology method provides a means for explicitly considering and exploring the sustainable use of natural resources in development process. While not a panacea, it does provide planners with information regarding the long-term resource implications of proposed policies, enabling the planner to identify and avoid unforeseen difficulties. This information is essential for sound planning and sustainable resource use.

The challenge for development today is implementing the concept of sustainability. While the existing tools in the planner's kit are still useful for their original purposes, they were not designed with the integration of many disciplines, interests, and types of information in mind and are unable to meet the difficult task which planners face. Adaptations of old tools, as well as the development of new tools, is necessary.

Most important may be the adoption of a systems perspective in approaching development problems. However, without a method for objectively considering and implementing such a perspective, sustainable resource use will not be realized.

REFERENCES

ARDA, "Communal Area Development Report No. 6: South Matabeleland. Project Proposal for Resettlement, Rural Development and Environmental Rehabilitation: Gwanda District, South Matabeleland," ARDA (Agriculture and Rural Development Authority), Bulawayo, Zimbabwe, 1983.

Asibey, E.D.A., "Wildlife as a Source of Protein in Africa South of the Sahara," Biological Conservation, vol. 6, no. 1, pp. 32-39, 1974.

Asibey, E.D.A., "Expected Effects of Land Use Patterns on Future Supplies of Bushmeat in Africa South of the Sahara," Environmental Conservation, vol. 4, no. 1, pp. 43-49, 1977.

Atherton, J.S., "The Evolution of a Donor Assistance Strategy for Livestock Programs in Subsaharan Africa," pp. 163-174 in J.R. Simpson and P. Evangelou, eds., Livestock Development in Subsaharan Africa, Westview Press, Boulder, CO, 1974.

Baker, J.J.W., and G.E. Allan, The Study of Biology, Addison-Wesley Publishing Co., Menlo Park, CA, 1977.

Banyikwa, F.F., A Quantitative Study of the Ecology of the Serengeti Short Grasslands, Ph.D. dissertation, University of Dar es Salaam, Tanzania, 1976.

Barton, K., "Bureau of Land Management," pp. 3-59 in R.L. Disilvestro, ed., Audubon Wildlife Report, Academic Press, Inc., New York, 1987.

Bazykin, A.D, "Volterra's System and the Michaelis-Mentin Equation" (in Russian), pp. 103-143 in V.A. Ratner, ed., Problems in Mathematical Genetics, USSR Acad. Sci. Novosibirsk, 1974.

Bekure, S., and N. Dyson-Hudson, "The Operation and Viability of the Second Livestock Development Project (1497-BT): Selected Issues," Ministry of Agriculture, Gabarone, Botswana, 1982.

Bell, R.H.V., "A Grazing Ecosystem in the Serengeti," Scientific American, vol. 224, no. 1, pp. 86-93, 1971.

Berwick, S., "The Gir Forest: An Endangered Ecosystem," American Scientist, vol. 64, no. 1, pp 28-40, 1976.

Berwick, S., R. Nisbet, and K.L. Reed, "Spatial Analysis for Determining 'Region-of-Influence' When Predicting Impacts on Wildlife and Other Resources," pp. 91-97 in R. Comer, ed., Issues and Technology in the Management of Impacted Western Wildlife, 1984.

Berwick, S., and B. Soewardi, "Guidelines for Applying the Environmental Impact Assessment Process to Resource Development in Indonesia," Winrock International, Morrilton, AR., 1991.

Blaisdell, J.P., and J.F. Pechanec, "Effects of Herbage Removal at Various Dates on Vigor of Bluebunch Wheatgrass and Arrowleaf Balsamroot, Ecology, vol. 30, pp. 298-305, 1949.

Brumer, J.S., The Process of Education, Harvard University Press, Cambridge, MA, 1960.

Chadwick, D. "Sagebrush Country: The American Outback," National Geographic, vol. 175, no. 1, pp. 52-83, 1989.

Chavanduka, D.M., Cattle Production, Mambo Press, Gweru, Zimbabwe, 1985.

Child, B., Economics of a Game and Cattle Ranch in the Lowveld of Zimbabwe, unpublished Ph.D. dissertation, Oxford University, U.K., 1988.

Child, G., M.B.E. Smith, and W. von Richter. "Tse-tse Control Hunting as a Measure of Large Mammal Population Trends in the Okavango Delta, Botswana," Mammalia, vol. 34, pp. 34-75, 1970.

Craddock, G.W., and C.K. Pearse, "Surface Run-off and Erosion on Granitic Mountain Soils of Idaho as Influenced by Range Cover, Soil Disturbance, Slope, and Precipitation Intensity," U.S. Department of Agriculture Circular 482, 1938.

Crawford, M.A., "A Re-evaluation of the Nutrient Role of Animal Products," in Proceedings of the World Conference on Animal Production, Sydney University Press, 1975.

Cumming, D.H.M., "Commercial and Safari Hunting in Zimbabwe," in Hudson, Drew, and Baskin, eds., Wildlife Production Systems, Cambridge University Press, Cambridge, England (in press), 1988.

Dasmann, R.F., Wildlife Biology, John Wiley and Sons, New York, 1981.

Dasmann, R.F., African Game Ranching, Pergamon Press, London, 1964.

Dittmer, H.J.N., "A Quantitative Study of the Roots and Root Hairs of a Winter Rye Plant (Secale cereale)," American Journal of Botany, vol. 24, no. 7, pp. 417-420, 1937.

Dregne & Grainger, Desertification: How People Make Deserts, How People Can Stop, and Why They Don't, Earthscan, Institute for International Environment and Development, London, 1982.

Dyer, A., The East African Members: The History of the East African Professional Members Association, Amwell Press, Clinton, NJ, 1979.

Dyksterhuis, E.V., "Condition and Management of Rangeland-Based Quantitative Ecology," Journal of Range of Management, vol. 2, pp. 104-115, 1949.

Ellis, V.E., and D.M. Swift, "Stability of African Pastoral Ecosystems: Alternate Paradigms and Implications for Development," Journal of Range Management, vol. 41, no. 6, pp. 450-459, 1988.

Economic Research Service, "World Food Needs and Availabilities 1988/89: Fall," ERS/USDA (U.S. Department of Agriculture), Washington, DC, 1989.

FAO Yearbooks. FAO, Rome. 1966-84.

Farvar, M.T., and J.P. Milton, The Careless Technology, Natural History Press, Garden City, NY, 1972.

Field, C.R., "Game Ranching in Africa," Applied Biology, vol. 4, pp. 63-99, 1979.

Flory, E.L., "Comparison of the Environment and Some Physiological Responses of Prairie Vegetation and Cultivated Maize," Ecology, vol. 17, no. 1, pp. 67-103, 1936.

Forrester, J.W., Industrial Dynamics, MIT Press, Cambridge, MA, 1961.

Forrester, J.W., Principles of Systems, MIT Press, Cambridge, MA, 1968.

Forrester, J.W., Urban Dynamics, MIT Press, Cambridge, MA, 1969.

Freeman, P.H., The Environmental Impact of a Large Tropical Reservoir, Smithsonian Institution, Washington, DC, 1974.

Freeman, P.H., "In-Service Training in National Resources and the Environment for AID Personnel," USAID/PM/TD, Washington, DC, 1988.

Golubev, G., and A.V. Biswas, Large Scale Water Transfers: Emerging Environmental and Social Experiences, Tycooly Publishing U.S.A., Riverton, NJ, 1985.

Goodloe, S., "Short Duration Grazing in Rhodesia," Journal of Range Management, vol. 22, pp. 369-373, 1969.

Harrison, C.M., "Effect of Cutting and Fertilizer Applications on Grass Development," Plant Physiology, vol. 6, no. 4, pp. 669-684, 1931.

Heady, H.F., Rangeland Management, McGraw-Hill, New York, 1975.

Holdgate, M., [article title], in C.S. Holling, ed., Adaptive Environmental Assessment and Management, John Wiley and Sons, New York, 1978.

Holling, C.S., ed., Adaptive Environmental Assessment and Management, John Wiley and Sons, New York, 1978.

Hunt, G.E., "A New Approach for Animal Agriculture," unpublished M.S. AGRODEV Canada, Inc., Ottawa, 1988.

IUCN, Scope of work to authors for Botswana National Conservation Strategy, 1986.

Jaffe, A., "Ranching on the Wildside," International Wildlife, vol. xx, pp. 4-13, 1976.

Jeffers, J.N.R., An Introduction to Systems Analysis: With Ecological Applications, Edward Arnold, Ltd., London, 1978.

Johnson, W.M., "Effect of Grazing Intensity on Vegetation and Cattle Gains on Ponderosa Pure-Bunchgrass Ranges of the Front Range of Colorado," U.S. Department of Agriculture Circular 929, 1953.

Leopold, A., Game Management, Chas. Scribners, New York, 1933.

Lamprey, H.F., "Ecological Separation of the Large Mammal Species in the Tarangire Game Reserve, Tanganyika," East Africa Wildlife Journal, vol 1, pp. 63-92, 1963.

Mabbut, J.A., "A New Global Assessment of the Status and Trends of Desertification," Environmental Conservation, vol. 11, no. 2, 1984.

Marks, S.A., "Buffalo Movements and Accessibility to a Community of Hunters in Zambia," East African World Journal, vol. 15, pp. 251-261, 1977.

May, R.M., Stability and Complexity in Model Ecosystems, Princeton University Press, Princeton, NJ, 1973.

McNaughton, S.J., "Grassland-Herbivore Dynamics," pp. 46-81 in A.R.E. Sinclair and M. Norton-Griffith, eds., Serengeti: Dynamics of an Ecosystem, University of Chicago Press, Chicago, 1979.

Meadows, D.H., "The Unavoidable A Priori," pp. 23-57 in J. Randers ed., Elements of the System Dynamics Method, MIT Press, Cambridge, MA, 1980.

Meadows, D.H., D.L. Meadows, J. Randers, and W. Behrens, III, The Limits to Growth, Universe Book, A Potomac Associates Book, NY, 1972.

Merrill, L.B., "A Variation of Deferred Rotation Grazing for Use under Southwest Range Conditions," Journal of Range Management, vol. 7, pp. 152-154, 1954.

Nelson, R., "Dryland Management: the "Desertification Problem," The World Bank, Environment Department Working Papers No. 8, 1988.

Nisbet, R., S. Berwick, and K.L. Reed, "Ecological Modeling of Sage Grouse Habitat Quality" in Proceedings of the 3rd International Economic Modeling Conference, Ft. Collins, CO, 1982.

Norton-Griffiths, M., "The Influence of Grazing, Browsing and Fire on the Vegetation Dynamics of the Serengeti," pp. 310-352 in A.R.E. Sinclair and M. Norton-Griffiths, eds., Serengeti: Dynamics of An Ecosystem, University of Chicago Press, Chicago, 1979.

Noy-Meir, I., "Stability of Grazing Systems: an Application of Predator-Prey Graphs," Journal of Ecology, vol. 63, pp. 459-481, 1975.

Orians, G.H., ed., Ecological Knowledge and Environmental Problem-Solving, NRC/NAS (National Research Council/National Academy of Science), National Academy Press, Washington, DC, 1986.

Oswalt, D.L., A.R. Bertrand, and M.R. Tell, "Influence of Nitrogen Fertilization and Clipping on Grass Roots," Proceedings of the Soil Science Society of America, vol. 23, pp. 228-230, 1959.

Palmer, W.L., "Ruffed Grouse Population Studies on Limited and Unlimited Areas," Transactions of the North American Wildlife Conference, vol. 21, pp. 338-345, 1956.

Pratt, D.J., and M.D. Gwynne, Rangeland Management and Ecology in East Africa, Hodder and Stoughton, London, 1977.

Pugh-Roberts, Professional DYNAMO Plus Reference Manual. Pugh-Roberts Associates, Inc., Cambridge, MA, 1986.

Rasmussen, D.I., "Biotic Communities of the Kaibab Plateau," Ecology Monographs, vol. 3, pp. 229-275, 1941.

Richardson, G.P., and A.L. Pugh, Introduction to System Dynamics Modeling with DYNAMO, MIT Press, Cambridge, MA, 1981.

Richmond, B., S. Peterson, and P. Vescuso, An Academic Users Guide to STELLA, High Performance Systems, Inc., Lyme, NH, 1987.

Roberts, E.B., "Strategies for Effective Implementation of Complex Corporate Models," Interfaces vol 8, no. 1, Pt. 1, 1977.

Roberts, E.B., Managerial Applications of System Dynamics, MIT Press, Cambridge, MA, 1980.

Roberts, N., D. Andersen, R. Deal, M. Garet, W. Shaffer, Introduction to Computer Simulation: The System Dynamics Approach, Addison-Wesley, Menlo Park, CA, 1983.

Robertson, J.H., "Effect of Frequent Clipping on the Development of Certain Grass Seedlings," Plant Physiology, vol. 8, no. 3, pp. 425-447, 1933.

Roux, P.W., and T.E. Skinner, "The Group-Camp System," Farming in South Africa, vol. 45, no. 10, pp. 25-28, 1970.

Savory, A. Holistic Resource Management, Island Press, Covelo, CA, 1988.

Schneider, H.K., "Livestock in African Culture and Society: a Historical Perspective," pp. 187-199 in J.R. Simpson and P. Evangelanou, eds., Livestock Development in Subsaharan Africa, Westview Press, Boulder, CO, 1984.

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

Seidensticker, J., "Managing Elephant Depredation in Agricultural and Forestry Projects," The World Bank, Washington, DC, 1984.

Sheffer, V.B., "The Rise and Fall of Reindeer Herd," Science Monthly, vol. 73, pp. 356-362, 1951.

Shively, S.B., and J.E. Weaver, "Amount of Underground Plant Materials in Different Grassland Climates," Nebraska Conservation Bulletin, 1939.

Silberbauer, G.B., Hunter and Habitat in the Central Kalahari Desert, Cambridge University Press, Cambridge, MA, 1981.

Simpson, J.R., "Problems and Constraints, Goals and Policy: Conflict Resolution and Development of Subsaharan Africa's Livestock Industry," pp. 1-20 in J.R. Simpson and P. Evangelou, eds., Livestock Development in Subsaharan Africa, Westview Press, Boulder, CO, 1984.

Sinclair, A.R.E., "Dynamics of the Serengeti Ecosystem: Process and Pattern," pp. 1-30 in A.R.E. Sinclair and M. Norton-Griffiths, eds., Serengeti: Dynamics of an Ecosystem, University of Chicago Press, Chicago, 1978.

Sinclair, A.R.E., "Does Interspecific Competition or Predation Shape the African Ungulate Community," Journal of Animal Ecology, vol. 54, pp. 899-918, 1985.

Sinclair, A.R.E., and M. Norton-Griffiths, "Does Competition or Facilitation Regulate Migrant Ungulate Populations in the Serengeti? A Test of Hypothesis," Oecologia, vol. 53, pp. 364-369, 1982.

Stoddard, L.A., and A.D. Smith, Range Management, McGraw-Hill, New York, 1955.

Style, C. "The Economics of Game Ranching in Zimbabwe," I.G.F. 15 Rue de Tehran, Paris, pp. 180-188, 1988.

Talbot et al., 1963. "The High Biomass of Wild Ungulates on East African Savannah," Trans North American Wildlife Conference, vol. 28, pp. 465-476, 1963 (1965 originally??????????????)

TAMS, "Environmental Assessment, Accelerated Mahaweli Development Programs, vol. I, Main Report," TAMS (Tippetts-Abbot-McCarthy-Stratton), New York, 1980.

Taylor, R.D., and B.H. Walker, "Comparisons of Vegetation Use and Herbivore Biomass on a Rhodesian Game and Cattle Ranch," Journal of Applied Ecology, vol. 15, pp. 565-581, 1979.

Thomas G. Editorial in Rangelands, vol. 9, Society for Range Management, Denver, 1987.

USAID, 1985. Report to the Administration.

US Forest Service, "Range Allotment Analysis Handbook," GPO, Washington, DC, 1980.

USHHS, "Annual Report of the Surgeon General," 1988.

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

von Richter, W., "Report to the Government of Botswana on a Survey of the Wild Animal Hide and Skin Industry," UNDP/FAO No. TA 2637, FAO (Food and Agriculture Organization of the United Nations), Rome, 1969.

Weiner, J.S., The Natural History of Man, Anchor Press/Doubleday, Garden City, NY, 1971.

Western, D., and V. Finch, "Cattle and Pastoralism: Survival and Production in Arid Lands," Human Ecology, vol. 14, no. 1, pp. 77-94, 1986.

WRI/IIED, World Resources Report, 1988-1989, World Resources Institute, Washington, DC, 1988.

Zerner, C. "The Flying Fisherman of Mandar," Cultural Survival Quarterly, vol. 11, no. 2, pp. 118-22, 1987.

ADDITIONAL READING

Crawford, M.A., M.M. Gale, M.H. Woodford, and N.M. Casperd, "Comparative Studies on Fatty Acid Composition of Wild and Domestic Meats," International Journal of Biochemistry, vol. 1, pp. 295-305, 1970.

Errington, P.L., "Predation and Vertebrate Populations," Quart. Rev. Bibl., vol. 21, pp. 144-245, 1946.

Forest Service, "Range Environmental Analysis Handbook," Rocky Mountain Region, FSH 2209.21, Forest Service, U.S. Department of Agriculture, 1968.

Starfield, A.M., and A.L. Bielock, Building Models for Conservation and Wildlife Management, Macmillan Publishing Co., New York, 1986.

Swartzman, G.L., and S.P. Kaluzny, Ecological Simulation Primer, Macmillan Publishing Co., New York, 1987.

Talbot, L.M., W.J.A. Payne, H.P. Ledger, L.D. Verdcourt, and M. Talbot, The Meat Production Potential of Wild Animals in Africa. A Review of Biological Knowledge, Technical Communication 16, Commonwealth Bureau of Animal Breeding and Genetics, Commonwealth Agriculture Bureau, Farnham Royal, U.K., 1965.

Taylor, C.R., "The Eland and the Oryx," Scientific American, vol. 220, no. 1, pp. 88-95, 1969