IIASA-PC-6

International Institute
for
Applied Systems Analysis

PROCEEDINGS
OF
IIASA PLANNING CONFERENCE
ON
ECOLOGICAL SYSTEMS

September 4 - 6, 1973

VOLUME II: APPENDICES

Schloss Laxenburg
2361 Laxenburg
Austria

The views expressed are those of the contributors and not necessarily those of the Institute.

The Institute assumes full responsibility for minor editorial changes made in grammar, syntax, or wording, and trusts that these modifications have not abused the sense of the writers' ideas.

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Introduction

No one voluntarily defines systems analysis. It can be represented as a new concept of understanding or a new technique of managing any complex system. Or it can be claimed to be simply a new label for an established way of thinking and doing. And ecology is the same. There was a time when ecology meant the study and management of the interrelations between organisms in their environment. Now it means so many things to so many people its definition and relevance are as confused as that of systems analysis. It is ironic justice that two such indefinable subjects have been so hailed as the panaceas for the problems of an industrialized world.

And yet, the problems are real. The resources that nourish the body and spirit of man do not seem as inexhaustible or as available as they once did. And our knowledge, techniques and institutions seem too fragmented to cope. Perhaps ecology and systems analysis are needed because of the failure of a strategy which has led to such fragmentation.

That is the reason behind the International Institute of Applied Systems Analysis--to examine and design resolutions to the problems which have emerged at interfaces between institutions, and between constituencies. In order to give this impossibly broad mandate practical definition and focus the Institute, as its first act, initiated a series of ten planning conferences to draw upon the knowledge and advice of the international scientific community. The Ecological Systems Planning Conference was one of these, and, like the others, was charged to review the field and identify the pressing issues of theory and application where IIASA could play a unique role.

IIASA is a new experiment in cooperation: not just between disciplines, which is difficult enough, but between different nations and cultures as well. As a consequence, its present status, constraints and potential are changing and evolving rapidly. It was scarcely possible during the short time of the conference, therefore, for the participants to do more than analyze the state of the field. Little time could be spent analyzing the state of IIASA, nor on the critical issue of relating these two to each other so that a coherent strategy and plan of action could be designed. These latter steps were taken after the series of conferences had been completed by the resident scientists of each project--first independently and then in iteration with other project groups and the director of IIASA.

These steps have been completed and the Conference Proceedings are designed to document the process. The Proceedings are presented in two parts. The first, "Summary and Recommendations," attempts to capture the essence, but not the details of our Conference by presenting the summary minutes, the proposed research program in ecology as developed after the Conference, an overview of IIASA's research strategy, and the proposed research programs that evolved from the other planning conferences which had the closest relation to ecology. In brief, therefore, this first section represents the present state and plans for ecological and environmental activities at IIASA. The second section provides the details of our Conference agenda, invited papers, formal submissions by participants and written commentaries generated by the participants during and after the Conference.

The conference participants played a key role in the development of each of the research proposals. Moreover, as the research plans are implemented, there will be a continuing effort to be flexible and to evolve different projects and even different strategies. It will be a measure of IIASA's future worth if the scientific community will be as willing to involve themselves in this process as they were in the first planning conferences. If they are not, the grand experiment will be a failure.

October 1973

C.S. Holling
Leader, Ecological Systems
Project

SECTION ONE

Conference Materials

APPENDIX I

Agenda
for
Research Planning Conference
on
ECOLOGICAL SYSTEMS

4 - 6 September 1973

Parkhotel Baden, Austria

Chairman: Professor C.S. Holling
Project Leader, IIASA

DAY 1 - IDENTIFYING ISSUES

Tuesday, September 4 (Conference Room, Parkhotel)

9:00 - 9:20	Welcome and Introduction of IIASA by the Director, Prof. Howard Raiffa
9:20 - 9:40	Chairman's Introduction - C.S. Holling, IIASA
9:40 - 10:00	Coffee Break
10:00 - 11:15	Topic: CONCEPTUAL ISSUES IN ECOSYSTEM ANALYSIS (I) Presentation: "Resilience and Stability in Ecological Systems," C.S. Holling, IIASA - Discussion -
11:15 - 12:30	Topic: DEVELOPMENT AND APPLICATION OF ECOLOGICAL MODELS (I) Presentation: "Where Resource and Environmental Simulation Models are Going Wrong," B.W. Mar, University of Washington. - Discussion -
12:30 - 2:00	Lunch
2:00 - 3:30	Topic: IDENTIFICATION OF CRITICAL AREAS FOR RESEARCH ON ECOLOGICAL SYSTEMS (I): Introduction Presentation: Position papers from the National Member Organizations (detailed agenda to be announced)
3:30 - 4:00	Coffee Break
4:00 - 5:30	Preliminary identification of priorities and pressing issues. This will be a group discussion based on the NMO statements and the list of issues provided by the invited speakers. It will furnish the framework for subsequent discussion on days two and three of the Conference.
7:00	Cocktails, followed by dinner at the Parkhotel

DAY 2 - PRIORITIES FOR ISSUES OF TECHNIQUE AND APPLICATION

Wednesday, September 5 (Conference Room, Parkhotel)

9:00 - 9:30 Review List of Priorities and Pressing Issues

9:30 - 12:30 Topic: TECHNICAL ISSUES OF ECOSYSTEM ANALYSIS (I)

Presentation: "Problems of Scale and Detail in Ecological Analysis," David W. Goodall, Utah State University.

- Discussion -

Coffee Break

Presentation: "Patchiness in the Sea; The Controlled Ecosystem Pollution Experiment"; J.H. Steele, Marine Laboratory, Aberdeen.

- Discussion -

12:25 Collection of participants' written commentary relating to Technical Issues of Ecosystem Analysis

12:30 - 2:00 Lunch

2:00 - 3:15 Topic: DEVELOPMENT AND APPLICATION OF ECOLOGICAL MODELS (II)

Presentation: "An Interdisciplinary Approach to Development of Watershed Simulation Models," C.J. Walters, University of British Columbia.

- Discussion -

3:15 - 3:40 Coffee Break

3:40 Collection of participants' written commentary relating to Development and Application of Ecological Models

3:45 - 5:30 Topic: IDENTIFICATION OF CRITICAL AREAS FOR RESEARCH ON ECOLOGICAL SYSTEMS (II): Problems of Technique and Application

- Discussion -

7:00 - 9:30 A "Heuriger" get-together.

Bus transportation will be arranged to bring participants and their wives to an informal dining and drinking establishment where local Austrian wine will help lubricate an international communication.

DAY 3 - PRIORITIES FOR CONCEPTUAL ISSUES AND SUMMARY

Thursday, September 6 (Schloss Laxenburg)

9:00	Departure by bus from Parkhotel to Schloss Laxenburg
9:30 - 10:45	Topic: CONCEPTUAL ISSUES IN ECOSYSTEM ANALYSIS (II) Presentation: "A Conceptual Framework for a Strategy to Mobilize Ecology and Other Sciences in Order to Solve Major Problems Related to Fisheries," Henry A. Regier, University of Toronto. - Discussion -
10:45 - 11:10	Coffee Break
11:10	Collection of participants' written commentary relating to Conceptual Issues in Ecosystem Analysis.
11:15 - 12:30	Topic: IDENTIFICATION OF CRITICAL AREAS FOR RESEARCH ON ECOLOGICAL SYSTEMS (III): Conceptual Problems - Group Discussion -
12:30 - 2:00	Picnic lunch and tour of IIASA facilities
2:00 - 3:45	Topic: IDENTIFICATION OF CRITICAL AREAS FOR RESEARCH ON ECOLOGICAL SYSTEMS (IV): Summary and Development of Specific Project Proposals - Group Discussion -
3:45	Collection of participants' written commentary relating to Specific Project Proposals
4:15 - 5:00	Discussion opened to members of the press
5:00	Cocktails, Schloss Laxenburg
6:30	Departure by bus from Schloss Laxenburg to Parkhotel

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

Research Planning Conference

"ECOLOGICAL SYSTEMS"

Parkhotel Baden, September 4th to 6th, 1973

List of Participants

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Chairman:

Prof. C.S. Holling
Project Leader - Ecology

IIASA STAFF (continued)

Prof. Howard Raiffa
Director

Prof. Alexandr Letov
Deputy Director

Prof. Wolfgang Haefele
Project Leader - Energy Systems

Dr. Andrei Bykov
Secretary to IIASA

Research Scholars:

Prof. Myron B. Fiering
(Engineering and Applied
Mathematics)

Prof. Alan Manne
(Energy Project)

Dr. Dixon Jones
(Resource Ecology)

Mr. William C. Clark
(Resource Ecology)

Mr. Zafar Rashid
(Resource Ecology)

Dr. David Bell
(Methodology)

Doz. Dr. R. Trappl
(Medical Systems)

Mrs. Ulrike H. Bigelow
(Rapporteur)

APPENDIX II

Introductory Remarks by the Institute Director

H. Raiffa

On behalf of the Institute, I would like to welcome you to this Planning Conference on Ecological Systems. This is part of a series of meetings which the Institute is holding to seek expert opinion in better defining the most promising directions for Institute research. The Institute hopes these conferences will provide a frank, open airing of viewpoints, opinions and controversies. To encourage such exchange, the minutes of the conference will reflect the varying sentiments of the participants but will avoid attribution of positions without prior approval of the speaker; however, remarks by the Chairman and by discussion leaders will be attributed. Any written statements from the participants will be welcome and shall be included in the final proceedings. The minutes of the conference will be distributed among the participants and the Council members.

Before outlining for you the Institute research plans, I would like briefly to sketch the history of IIASA. Early in 1967, Mr. McGeorge Bundy, representing the President of the United States, met in Moscow with Dr. Jerman Gvishiani, Deputy Chairman of the State Committee of the U.S.S.R. for Science and Technology. Their discussions dealt with a proposal of the President "to explore the possibility of establishing an international center for studies of the common problems of advanced societies." That meeting opened a five-year period of planning conferences and multi-national negotiations held under the Chairmanship of Lord Solly Zuckerman of the United Kingdom and convoked with the goal of establishing such a center.

At the risk of slighting many people who contributed greatly to the planning for the Institute, it is only just to mention that major roles were played by Monsieur Pierre Aigrain of the French government, Prof. Philip Handler of the U.S. National Academy of Sciences, Dr. O. Leupold of the German Democratic Republic, Signor Aurelio Peccei of Italy, Dr. Friedrich Schneider of the Max Planck Gesellschaft, Prof. D. Smolenski of the Polish Academy of Sciences, as well as by Messrs. Bundy, Gvishiani, and Zuckerman. A representative national scientific institution from each of their countries and, in early 1972, from Bulgaria, Canada, Czechoslovakia, and Japan were invited to join the Institute, bringing the founding membership to twelve.

On 4 October 1972, these founding members signed the Charter creating IIASA as a non-governmental international institute; at the same time, they selected Laxenburg, Austria, to be the site of the Institute headquarters. The Austrian government had proposed to renovate the former Habsburg palace there, and the first set of offices was completed on schedule in June, 1973. Work on another wing of Schloss Laxenburg is in progress and should be finished by the end of 1973. We expect completion of the first major phase of renovations by the end of 1974, with a second phase to begin in 1975.

The timetable for development of the Institute has three overlapping phases: organization of the Institute administration (October, 1972 through June, 1973); research planning conferences, of which this is one (July through October, 1973); and expansion of the research program (already begun and continuing in the future at an accelerated pace).

The number of scientists in residence will treble between now and September, 1975, when approximately ninety scholars will be working in Laxenburg. These scientists will be chosen with consideration of geographical distribution among the member nations. They will be invited to work at the Institute for short terms or for periods up to three years, with most coming for one year.

In addition to normal administrative support for the scholars, the Institute is developing scientific support to include three essential services: an in-house library connected with libraries in Vienna and abroad, an information distribution system, and computer facilities. The Institute currently has time-sharing arrangements with the Honeywell-Bull Mark I and Mark III systems, using terminals already installed in the castle. The computer section is presently selecting an appropriate mini-computer, and investigating the possibility of eventually purchasing a large, primary machine.

This gives you an overview of the background and physical structure of the Institute. I would now like to describe the Institute plans for its research program, and then finally, to express our goals for this conference.

The Institute has two branches: the Council, which is responsible for broad policy, and the Directorate, which implements, directs, and administers the research program. Planning for this program has gone through various stages of refinement. The Council has determined what the broad areas of Institute research are to be, and now, using ideas and suggestions gleaned from the research planning conferences, the Director, Deputy Director, and other IIASA research leaders will propose for approval by the Council a more formal research strategy. In the interim, the Directorate has had a partial mandate to invite scholars to begin work this year.

The Council outlined ten broad research areas with overlapping boundaries. To overcome problems which the breadth of these areas could create, the Institute chose two approaches. Its scholars will work on topics with obvious interrelations, and, in addition to this in-house research, will exploit the infrastructures of other groups such as the national member organizations, United Nations groups, and other national and international institutions engaged in projects related to IIASA interests.

However, the Institute will be neither a project-oriented consulting group, nor merely a data-collecting institution. Rather, it will attempt to strike a balance between methodological and applied studies in seeking solutions for real world problems.

It is further essential that we maintain a healthy geographic balance across the research team structure. The teams must be so designed that scientists of different nationalities supplement each other, communicate, and learn from each other. The structure should be such that this occurs naturally, with guidance from the leadership, but without constant interference.

As important, and perhaps as difficult as the balance of nationalities, is the balance of disciplines. Applied and methodological researchers, applied mathematicians and engineers, statisticians and organizational theorists, social scientists and operations researchers, economists and decision analysts have much to contribute to one another. IIASA projects should be structured so that each group feels vitally a need for the others. We feel that perhaps the best way to achieve this is through concentration upon applied projects in which the disparate disciplines must interact with each other in order to produce concrete results.

During the course of this conference, the Institute expects you to voice your opinions, to map out alternate designs for approaching the research, to isolate theoretical research topics within the area of ecological systems to suggest ways to collaborate with other groups, and to discuss possibilities for choosing a concrete problem for analysis if this course appears fruitful. We further hope that the conference will produce preliminary suggestions for a basic library in the ecology area, and guidelines for necessary computer support.

The conference participants should explore the value of reanalyses by IIASA scientists of current outside projects, or the desirability of retrospective critiques of past projects. Here IIASA could bring to bear its wealth of cross-cultural and cross-disciplinary viewpoints in seeking out lessons from other projects which could improve its own research efforts in ecological systems.

We should also discuss what sort of people could most usefully be involved in our ecology effort. For example, how might we benefit from the contributions of economists, physicists, biologists, meteorologists, engineers, lawyers, organizational experts, or geographers? Along these lines, we would hope to consider the proper mix of in-house personnel and external contacts for carrying out our objectives.

Finally the conference participants should identify points of natural contact between the ecology project and other Institute projects on energy and water resources.

Valuable suggestions have emerged from our previous conferences. We feel that the discussions in this planning conference will further identify what we might term "the distinctive competence" of IIASA. Only then can we shape a research program for the Institute which will make a unique contribution to research in the area of Ecological Systems.

SECTION TWO

Invited Papers

This Section contains papers presented by the invited speakers at the Conference. Since several of the papers have not yet appeared in the formal literature, we ask that none be quoted without express written permission from the authors.

APPENDIX III

Resilence and Stability of Ecological Systems

C. S. Holling

Resilience and Stability of Ecological Systems

C.S. Holling

INTRODUCTION

Individuals die, populations disappear, and species become extinct. That is one view of the world. But another view of the world concentrates not so much on presence or absence as upon the numbers of organisms and the degree of constancy of their numbers. These are two very different ways of viewing the behavior of systems and the usefulness of the view depends very much on the properties of the system concerned. If we are examining a particular device designed by the engineer to perform specific tasks under a rather narrow range of predictable external conditions, we are likely to be more concerned with consistent nonvariable performance in which slight departures from the performance goal are immediately counteracted. A quantitative view of the behavior of the system is, therefore, essential. With attention focused upon achieving constancy, the critical events seem to be the amplitude and frequency of oscillations. But if we are dealing with a system profoundly affected by changes external to it, and continually confronted by the unexpected, the constancy of its behavior becomes less important than the persistence of the relationships. Attention shifts, therefore, to the qualitative and to questions of existence or not.

Our traditions of analysis in theoretical and empirical ecology have been largely inherited from developments in classical physics and its applied variants. Inevitably, there has been a tendency to emphasize the quantitative rather than the qualitative, for it is important in this tradition to know not just that a quantity is larger than another quantity, but precisely how much larger. It is similarly important, if a quantity fluctuates, to know its amplitude and period of fluctuation. But this orientation may simply reflect an analytic approach developed in one area because it was useful and then transferred to another where it may not be.

Our traditional view of natural systems, therefore, might well be less a meaningful reality than a perceptual convenience. There can in some years be more owls and fewer mice and in others, the reverse. Fish populations wax and wane as a natural condition, and insect populations can range over extremes that only logarithmic transformations can easily illustrate. Moreover, over distinct areas, during long or short periods of time, species can completely disappear and then reappear. Different and useful insight might be obtained, therefore, by viewing the behaviour of ecological systems in terms of the probability of extinction of their elements, and by shifting emphasis from the equilibrium states to the conditions for persistence.

An equilibrium centered view is essentially static and provides little insight into the transient behaviour of systems that are not near the equilibrium. Natural, undisturbed systems are likely to be continually in a transient state; they will be equally so under the influence of man. As man's numbers and economic demands increase, his use of resources shifts equilibrium states and moves populations away from equilibria. The present concerns for pollution and endangered species are specific signals that the well-being of the world is not adequately described by concentrating on equilibria and conditions near them. Moreover, strategies based upon these two different views of the world might well be antagonistic. It is at least conceivable that the effective and responsible effort to provide a maximum sustained yield from a fish population or a nonfluctuating supply of water from a watershed (both equilibrium-centered views) might paradoxically increase the chance for extinctions.

The purpose of this review is to explore both ecological theory and the behaviour of natural systems to see if different perspectives of their behaviour can yield different insights useful for both theory and practice.

Some Theory

Let us first consider the behaviour of two interacting populations: a predator and its prey, a herbivore and its resource, or two competitors. If the interrelations are at all regulated we might expect a disturbance of one or both populations in a constant environment to be followed by fluctuations that gradually decrease in amplitude. They might be represented as in Figure 1, where the fluctuations of each population over time are shown as the sides of a box. In this example the two populations in some sense are regulating each other, but the lags in the response generate a series of oscillations whose amplitude gradually reduces to a constant and sustained value for each population. But if we are also concerned with persistence we would like to know not just how the populations behave from one particular pair of starting values, but from all possible pairs since there might well be combinations of starting populations for which ultimately the fate of one or other of the populations is extinction. It becomes very difficult on time plots to show the full variety of responses possible, and it proves convenient to plot a trajectory in a phase plane. This is shown by the end of the box in Figure 1 where the two axes represent the density of the two populations. (Figure 1 near here)

The trajectory shown on that plane represents the sequential change of the two populations at constant time intervals. Each point represents the unique density of each population at a particular point in time and the arrows indicate the direction of change over time. If oscillations are damped, as in the case shown, then the trajectory is represented as a closed spiral that eventually reaches a stable equilibrium.

We can imagine a number of different forms for trajectories in the phase plane (Figure 2). Figure 2a shows an open spiral which would represent situations where fluctuations gradually increase in amplitude. The small arrows are added to suggest that this condition holds no matter what combination of populations initiates the trajectory. In Figure 2b the trajectories are closed and given any starting point eventually return to that point.

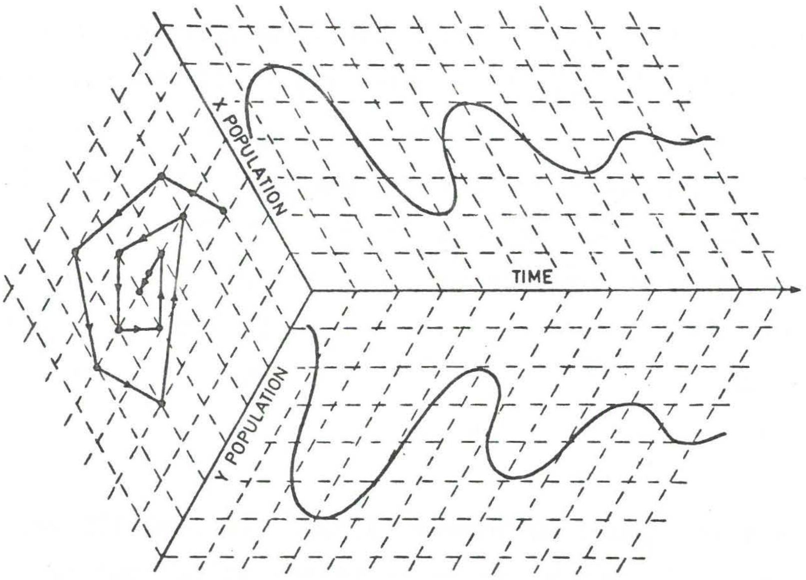

FIGURE 1. Derivation of a Phase Plane Showing the Changes in Numbers of Two Populations Over Time

It is particularly significant that each starting point generates a unique cycle and there is no tendency for points to converge to a single cycle or point. This can be termed "neutral stability" and it is the kind of stability achieved by an imaginary frictionless pendulum. (Figure 2 near here) MSP 5

Figure 2c represents a stable system similar to that of Figure 1, in which all possible trajectories in the phase plane spiral into an equilibrium. These three examples are relatively simple and, however relevant for classical stability analysis, may well be theoretical curiosities in ecology. Figures 2d-2f add some complexities. In a sense Figure 2d represents a combination of a and c, with a region in the center of the phase plane within which all possible trajectories spiral inwards to equilibrium. Those outside this region spiral outwards and lead eventually to extinction of one or the other populations. This is an example of local stability in contrast to the global stability of Figure 2c. I designate the region within which stability occurs as the domain of attraction, and the line that contains this domain as the boundary of the attraction domain.

The trajectories in Figure 2e behave in just the opposite way. There is an internal region within which the trajectories spiral out to a stable limit cycle and beyond which they spiral inwards to it. Finally, a stable node is shown in Figure 2f in which there are no oscillations and the trajectories approach the node monotonically. These six figures could be combined in an almost infinite variety of ways to produce several domains of attraction within which there could be a stable equilibrium, a stable limit cycle, a stable node, or even neutrally stable orbits. Although I have presumed a constant world throughout, in the presence of random fluctuations of parameters or of driving variables (Walters 39), any one trajectory could wander with only its general form approaching the shape of the trajectory shown. These added complications are explored later when we consider real systems. For the moment, however, let us review theoretical treatments in the light of the possibilities suggested in Figure 2.

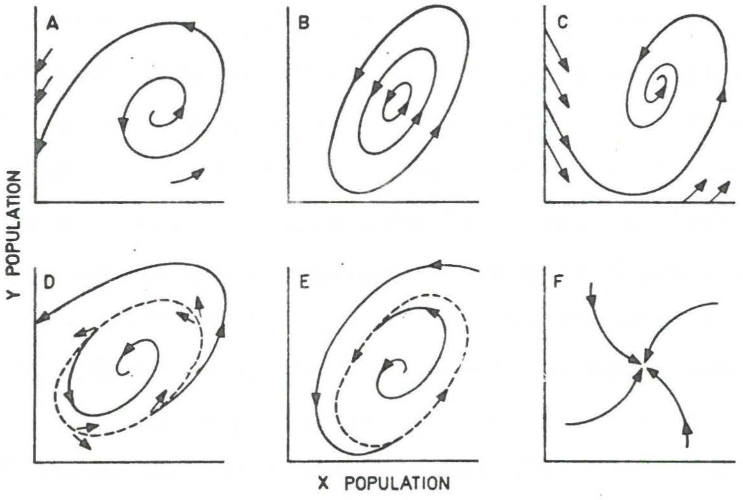

FIGURE 2. Examples of Possible Behaviours of Systems in a Phase Plane; a. Unstable equilibrium, b. Neutrally stable cycles, c. Stable equilibrium, d. Domain of attraction, e. Stable limit cycle, f. Stable node

The present status of ecological stability theory is very well summarized in a number of analyses of classical models, particularly May's (23-25) insightful analyses of the Lotka-Volterra model and its expansions, the graphical stability analyses of Rosenzweig (33, 34), and the methodological review of Lewontin (20).

May (24) reviews the large class of coupled differential equations expressing the rate of change of two populations as continuous functions of both. The behaviour of these models results from the interplay between (a) stabilizing negative feedback or density-dependent responses to resources and predation, and (b) the destabilizing effects produced by the way individual predators attack and predator numbers respond to prey density (termed the functional and numerical responses as in Holling 11). Various forms have been given to these terms; the familiar Lotka-Volterra model includes the simplest and least realistic, in which death of prey is caused only by predation, predation is a linear function of the product of prey and predator populations, and growth of the predator population is linearly proportional to the same product. This model generates neutral stability as in Figure 2b, but the assumptions are very unrealistic since very few components are included, there are no explicit lags or spatial elements, and thresholds, limits, and nonlinearities are missing.

These features have all been shown to be essential properties of the predation process (Holling 12, 13) and the effect of adding some of them has been analysed by May (24). He points out that traditional ways of analysing the stability properties of models using analytical or graphical means (Rozenzweig & MacArthur 33, Rosenzweig 34, 35) concentrate about the immediate neighbourhood of the equilibrium. By doing this, linear techniques of analysis can be applied that are analytically tractable. Such analyses show that with certain defined sets of parameters stable equilibrium points or nodes exist (such as Figure 2c), while for other sets they do not, and in such cases the system is, by default, presumed to be unstable, as in Figure 2a. May (24), however, invokes a little used theorem of Kolomogorow (Minorsky 26) to show that all these models have either a stable equilibrium point or a stable limit cycle (as in Figure 2e). Hence he concludes that the conditions presumed by linear analysis are unstable, and in fact must lead to stable limit cycles. In every instance, however, the models are globally rather than locally stable, limiting their behaviour to that shown in either Figures 2c or 2e.

There is another tradition of models that recognizes the basically discontinuous features of ecological systems and incorporates explicit lags. Nicholson and Bailey initiated this tradition when they developed a model using the output of attacks and survivals within one generation as the input for the next (29). The introduction of this explicit lag generates oscillations that increase in amplitude until one or other of the species becomes extinct (Figure 2a). Their assumptions are as unrealistically simple as Lotka's and Volterra's; the instability results because the number of attacking predators at any moment is so much a consequence of events in the previous generation that there are "too many" when prey are declining and "too few" when prey are increasing. If a lag is introduced into the Lotka-Volterra formulation (Wangersky & Cunningham 40) the same instability results.

The sense one gains, then, of the behaviour of the traditional models is that they are either globally unstable or globally stable, that neutral stability is very unlikely, and that when the models are stable a limit cycle is a likely consequence.

Many, but not all, of the simplifying assumptions have been relaxed in simulation models, and there is one example (Holling & Ewing 14) that joins the two traditions initiated by Lotka-Volterra and Nicholson and Bailey and, further, includes more realism in the operation of the stabilizing and destabilizing forces. These modifications are described in more detail later; the important features accounting for the difference in behaviour result from the introduction of explicit lags, a functional response of predators that rises monotonically to a plateau, a nonrandom (or contagious) attack by predators, and a minimum prey density below which reproduction does not occur. With these changes a very different pattern emerges that conforms most closely to Figure 2d. That is, there exists a domain of attraction within which there is a stable equilibrium; beyond that domain the prey population becomes extinct. Unlike the Nicholson and Bailey model, the stability becomes possible, although in a limited region, because of contagious attack. (Contagious attack implies that for one reason or another some prey have a greater probability of being attacked than others, a condition that is common in nature (Griffiths & Holling 9).) The influence of contagious attack becomes significant whenever predators become abundant in relation to the prey, for then the susceptible prey receive the burden of attention, allowing more prey to escape than would be expected by random contact. This "inefficiency" of the predator allows the system to counteract the destabilizing effects of the lag.

If this were the only difference the system would be globally stable, much as Figure 2c. The inability of the prey to reproduce at low densities, however, allows some of the trajectories to cut this reproduction threshold, and the prey become extinct. This introduces a lower prey density boundary to the attraction domain and, at the same time, a higher prey density boundary above which the amplitudes of the oscillations inevitably carry the population below the reproduction threshold. The other modifications in the model, some of which have been touched on above, alter this picture in degree only. The essential point is that a more realistic representation of the behaviour of interacting populations indicates the existence of at least one domain of attraction. It is quite possible, within this domain, to imagine stable equilibrium points, stable nodes, or stable limit cycles. Whatever the detailed configuration, the existence of discrete domains of attraction immediately suggests important consequences for the persistence of the system and the probability of its extinction.

Such models, however complex, are still so simple that they should not be viewed in a definitive and quantitative way. They are more powerfully used as a starting point to organize and guide understanding. It becomes valuable, therefore, to ask what the models leave out and whether such omissions make isolated domains of attraction more or less likely.

Theoretical models generally have not done well in simulataneously incorporating realistic behaviour of the processes involved, randomness, spatial heterogeneity, and an adequate number of dimensions or state variables. This situation is changing very rapidly as theory and empirical studies develop a closer technical partnership. In what follows I refer to real world examples to determine how the four elements that tend to be left out might further affect the behaviour of ecological systems.

SOME REAL WORLD EXAMPLES

Self-Contained Ecosystems

In the broadest sense, the closest approximation we could make of a real world example that did not grossly depart from the assumptions of the theoretical models would be a self-contained system that was fairly homogenous and in which climatic fluctuations were reasonably small. If such systems could be discovered they would reveal how the more realistic interaction of real world processes could modify the patterns of systems behaviour described above. Very close approximations to any of these conditions are not likely to be found, but if any exist, they are apt to be fresh water aquatic ones. Fresh water lakes are reasonably contained systems, at least within their watersheds; the fish show considerable mobility thoughout, and the properties of the water buffer the more extreme effects of climate. Moreover, there have been enough documented man-made disturbances to liken them to perturbed systems in which either the parameter values or the levels of the constituent populations are changed. In a crude way, then, the lake studies can be likened to a partial exploration of a phase space of the sorts shown in Figure 2. Two major classes of disturbances have occurred: first, the impact of nutrient enrichment from man's domestic and industrial wastes and second, changes in fish populations by harvesting.

The paleolimnologists have been remarkably successful in tracing the impact of man's activities on lake systems over surprisingly long periods. For example, Hutchinson (17) has reconstructed the series of events occurring in a small crater lake in Italy from the last glacial period in the Alps (2000 to 1800 BC) to the present. Between the beginning of the record and Roman times the lake had established a trophic equilibrium with a low level of productivity which persisted in spite of dramatic changes in surroundings from Artemesia steppe, through grassland, to fir and mixed oak forest. Then suddenly the whole aquatic system altered. This alteration towards eutrophication seems to have been initiated by the construction of the Via Cassia about 171 BC, which caused a subtle change in the hydrographic regime. The whole sequence of environmental changes can be viewed as changes in parameters or driving variables, and the long persistence in the face of these major changes suggests that natural systems have a high capacity to absorb change without dramatically altering. But this resilient character has its limits, and when the limits are passed, as by the construction of the Roman highway, the system rapidly changes to another condition.

More recently the activities of man have accelerated and limnologists have recorded some of the responses to these changes. The most dramatic change consists of blooms of algae in surface waters, an extraordinary growth triggered in most instances, by nutrient additions from agricultural and domestic sources.

While such instances of nutrient addition provide some of the few examples available of perturbation effects in nature, there are no controls and the perturbations are exceedingly difficult to document. Nevertheless, the qualitative pattern seems consistent, particularly in those lakes (Edmundson 4 and Hasler 10) to which sewage has been added for a time and then diverted elsewhere. This pulse of disturbance characteristically triggers periodic algal blooms, low oxygen conditions, the sudden disappearance of some plankton species, and appearance of others. As only one example, the nutrient changes in Lake Michigan (Beeton 2) have been accompanied by the replacement of the cladoceran Bosmina coregoni by B. Longirostris, Diaptomus oregonensis has become an important copepod species, and a brackish water copepod Eurytemora affinis is a new addition to the zooplankton.

In Lake Erie, which has been particularly affected because of ist shallowness and intensity of use, the mayfly Hexagenia, which originally dominated the benthic community, has been almost totally replaced by oligochetes. There have been blooms of the blue green alga Melosira binderana, which had never been reported from the United States until 1961 but now comprises as much as 99% of the total phytoplankton around certain islands. In those cases where sewage has been subsequently diverted there is a gradual return to less extreme conditions, the slowness of the return related to the accumulation of nutrients in sediments.

The overall pattern emerging from these examples is the sudden appearance or disappearance of populations, a wide amplitude of fluctuations, and the establishment of new domains of attraction.

The history of the Great Lakes provides not only some particularly good information on responses to man-made enrichment, but also on responses of fish populations to fishing pressure. The eutrophication experience touched on above can be viewed as an example of systems changes in driving variables and parameters, whereas the fishing example is more an experiment in changing state variables. The fisheries of the Great Lakes have always selectively concentrated on abundant species that are in high demand. Prior to 1930, before eutrophication complicated the story, the lake sturgeon in all the Great Lakes, the lake herring in Lake Erie, and the lake whitefish in Lake Huron were intensively fished (Smith 37). In each case the pattern was similar: a period of intense exploitation during which there was a prolonged high level harvest, followed by a sudden and precipitous drop in populations. Most significantly, even though fishing pressure was then relaxed none of these populations showed any sign of returning to their previous levels of abundance. This is not unexpected for sturgeon because of their slow growth and late maturity, but it is unexpected for herring and whitefish. The maintenance of these low populations in recent times might be attributed to the increasingly unfavourable chemical or biological environment, but in the case of the herring, at least, the declines took place in the early 1920s before the major deterioration in environment occurred. It is as if the population had been shifted by fishing pressure from a domain with a high equilibrium to one with a lower one. This is clearly not a condition of neutral stability as suggested in Figure 2b since once the populations were lowered to a certain point the decline continued even though fishing pressure was relaxed. It can be better interpreted as a variant of Figure 2d where populations have been moved from one domain of attraction to another.

Since 1940 there has been a series of similar catastrophic changes in the Great Lakes that has led to major changes in the fish stocks. Beeton (2) provides graphs summarizing the catch statistics in the lakes for many species since 1900. Lake trout, whitefish, herring, walleye, sauger, and blue pike have experienced precipitous declines of populations to very low values in all of the lakes. The changes generally conform to the same pattern. After sustained but fluctuating levels of harvest the catch dropped dramatically in a span of a very few years, covering a range of from one to four orders of magnitude. In a number of examples particularly high catches were obtained just before the drop. Although catch statistics inevitably exaggerate the step-like character of the pattern, populations must have generally behaved in the way described.

The explanations for these changes have been explored in part, and involve various combinations of intense fishing pressure, changes in the physical and chemical environment, and the appearance of a foreign predator (the sea lamprey) and foreign competitors (the alewife and carp). For our purpose the specific cause is of less interest than the inferences that can be drawn concerning the resilience of these systems and their stability behavior. The events in Lake Michigan provide a typical example of the pattern in other lakes (Smith 37). The catch of lake trout was high, but fluctuated at around six million pounds annually from 1898 to 1940. For four years catches increased noticeably and then suddenly collapsed to near extinction by the 1950s due to a complete failure of natural reproduction. Lake herring and whitefish followed a similar pattern (Beeton 2, Figure 7). Smith (37) argues that the trigger for the lake trout collapse was the appearance of the sea lamprey that had spread through the Great Lakes after the construction of the Velland Canal. Although lamprey populations were extremely small at the time of the collapse, Smith argues that even a small mortality, added to a commercial harvest that was probably at the maximum for sustained yield, was sufficient to cause the collapse. Moreover, Ricker (31) has shown that fishing pressure shifts the age structure of fish populations towards younger ages. He demonstrated that a point can come where only slight increases in mortality can trigger a collapse of the kind noted for lake trout. In addition the lake trout was coupled in a network of competitive and predatory interconnections with other species, and pressures on these might have contributed as well.

Whatever the specific causes, it is clear that the precondition for the collapse was set by the harvesting of fish, even though during a long period there were no obvious signs of problems. The fishing activity, however, progressively reduced the resilience of the system so that when the inevitable unexpected event occurred, the populations collapsed. If it had not been the lamprey, it would have been something else: a change in climate as part of the normal pattern of fluctuation, a change in the chemical or physical environment or a change in competitors or predators. These examples again suggest distinct domains of attraction in which the populations forced close to the boundary of the domain can then flip over it.

The above examples are not isolated ones. In 1939 an experimental fishery was started in Lake Windermere to improve stocks of salmonids by reducing the abundance of perch (a competitor) and pike (a predator). Perch populations were particularly affected by trapping and the populations fell drastically in the first three years. Most significantly, although no perch have been removed from the North Basin since 1947, populations have still not shown any tendency to return to their previous level (Le Cren et al 19).

The same patterns have even been suggested for terrestrial systems. Many of the arid cattle grazing lands of the western United States have gradually become invaded and dominated by shrubs and trees like mesquite and cholla. In some instances grazing and the reduced incidence of fire through fire prevention programs allowed invasion and establishment of shrubs and trees at the expense of grass. Nevertheless, Glendening (8) has demonstrated, from data collected in a 17-year experiment in which intensity of grazing was manipulated, that once the trees have gained sufficient size and density to completely utilize or materially reduce the moisture supply, elimination of grazing will not result in the grassland reestablishing itself. In short, there is a level of the state variable "trees" that, once achieved, moves the system from one domain of attraction to another. Return to the original domain can only be made by an explicit reduction of the trees and shrubs.

These examples point to one or more distinct domains of attraction in which the important point is not so much how stable they are within the domain, but how likely it is for the system to move from one domain into another and so persist in a changed configuration.

This sampling of examples is inevitably biased. There are few cases well documented over a long period of time, and certainly some systems that have been greatly disturbed have fully recovered their original state once the disturbance was removed. But the recovery in most instances is in open systems in which reinvasion is the key ingredient. These cases are discussed below in connection with the effects of spatial heterogeneity. For the moment I conclude that distinct domains of attraction are not uncommon within closed systems. If such is the case, then further confirmation should be found from empirical evidence of the way processes which link organisms operate, for it is these processes that are the cause of the behavior observed.

Process Analysis

One way to represent the combined effects of processes like fecundity, predation, and competition is by using Ricker's (30) reproduction curves. These simply represent the population in one generation as a function of the population in the previous generation, and examples are shown in Figures 3a, c, and e. In the simplest form, and the one most used in practical fisheries management (Figure 3a), the reproduction curve is dome-shaped.

When it crosses a line with slope 1 (the straight line in the figures) an equilibrium condition is possible, for at such cross-overs the population in one generation will produce the same number in the next. It is extremely difficult to detect the precise form of such curves in nature, however; variability is high, typically data are only available for parts of any one curve, and the treatment really only applies to situations where there are no lags. It is possible to deduce various forms of reproduction curves, however, by disaggregating the contributions of fecundity and mortality. The three lower graphs in Figure 3b, 3d, and 3f represent this disaggregation of their counterpart reproduction curves. The simplest types of reproduction curve (Figure 3a) can arise from a mortality that regularly increases with density and either a constant fecundity or a declining one. With fecundity expressed as the percentage mortality necessary to just balance reproduction, the cross-over point of the curves represents the equilibrium condition. But we know that the effects of density on fecundity and mortality can be very much more complicated. (insert Figure 3 near here) MSP 18

Mortality from predation, for example, has been shown to take a number of classic forms (Holling 11, 13). The individual attack by predators as a function of prey density (the functional response to prey density) can increase with a linear rise to a plateau (type 1), a concave or negatively accelerated rise to a plateau (type 2), or an S-shaped rise to a plateau (type 3). The resulting contribution to mortality from these responses can therefore show ranges of prey density in which there is direct density dependence (negative feedback from the positively accelerated portions of the type 3 response), density independence (the straight line rise of type 1), and inverse dependence (the positive feedback from the negatively accelerated and plateau portions of the curves). There are, in addition, various numerical responses generated by changes in the number of predators as the density of their prey increases. Even for those predators whose populations respond by increasing, there often will be a limit to the increase set by other conditions in the environment. When populations are increasing they tend to augment the negative feedback features (although with a delay), but

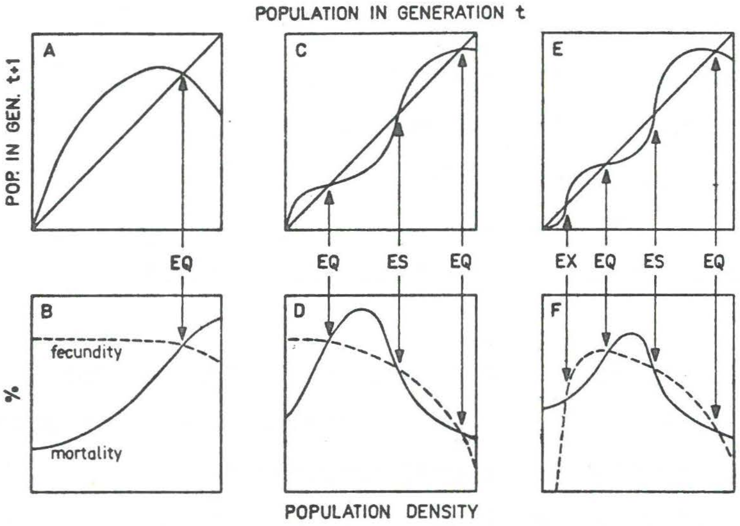

FIGURE 3. Examples of Various Reproduction Curves (a, c and e) and Their Derivation from the Contributions of Fecundity and Mortality (b, d and f)

when populations are constant, despite increasing prey density, the percent mortality will inevitably decline since individual attack eventually saturates at complete satiation (the plateaux of all three functional responses). In Figures 3d and 3f the mortality curves shown summarize a common type. The rising or direct density-dependent limb of the curve is induced by increasing predator populations and by the reduced intensity of attack at low densities, shown by the initial positively accelerated portion of the S-shaped type 3 response. Such a condition is common for predators with alternate prey, both vertebrates (Holling 14) and at least some invertebrates (Steele 38). The declining inverse density-dependent limb is induced by satiation of the predator and a numerical response that has been reduced or stopped.

Fecundity curves that decline regularly over a very wide range of increasing population densities (as in Figure 3d) are common and have been referred to as Drosophila-type curves (Fujita 6) This decline in fecundity is caused by increased competition for oviposition sites, interference with mating, and increased sterility. The interaction between a dome-shaped mortality curve and a monotonically decreasing fecundity curve can generate equilibrium conditions (Figure 3d). Two stable equilibria are possible, but between these two is a transient equilibrium designated as the escape threshold (ES in Figure 3). Effects of random changes on populations or parameters could readily shift densities from around the lower equilibrium to above this escape threshold, and in these circumstances populations would inevitably increase to higher equilibrium.

The fecundity curves are likely to be more complex, however, since it seems inevitable that at some very low densities fecundity will decline because of difficulties in finding mates and the reduced effect of a variety of social facilitation behaviors. We might even logically conclude that for many species there is a minimum density below which fecundity is zero. A fecundity curve of this Allee-type (Fujita 6) has been empirically demonstrated for a number of insects (Watt 42) and is shown in Figure 3f. Its interaction with the dome-shaped mortality curve can add another transient equilibrium, the extinction threshold (EX in Figure 3f). With this addition there is a lower density such that if populations slip below it they will proceed inexorably to extinction. The extinction threshold is particularly likely since it has been shown mathematically that each of the three functional response curves will intersect with the ordinate of percent predation at a value above zero (Holling 13).

Empirical evidence, therefore, suggests that realistic forms to fecundity and mortality curves will generate sinuous reproduction curves like those in Figures 3c and 3e with the possibility of a number of equilibrium states, some transient and some stable. These are precisely the conditions that will generate domains of attraction, with each domain separated from others by the extinction and escape thresholds. This analysis of process hence adds support to the field observations discussed earlier.

The behavior of systems in phase space cannot be completely understood by the graphical representations presented above. These graphs are appropriate only when effects are immediate; in the face of the lags that generate cyclic behavior the reproduction curve should really produce two values for the population in generation $t + 1$ for each value of the population in generation t. The graphical treatment of Rosensweig & Mac Arthur (33) to a degree can accommodate these lags and cyclic behavior. In their treatment they divide phase planes of the kind shown in Figure 2 into various regions of increasing and decreasing x and y populations. The regions are separated by two lines, one representing the collection of points at which the prey population does not change in density ($dx/dt = 0$, the prey isocline) and one in which the predator population does not so change ($dy/dt = 0$, the predator isocline). They deduce that the prey isocline will be dome-shaped for much the same reason as described for the fecundity curves of Figure 3f. The predator isocline, in the simplest condition, is presumed to be vertical, assuming that only one fixed level of prey is necessary to just maintain the predator population at a zero instantaneous rate of change.

Intersection of the two isoclines indicates a point where both populations are at equilibrium. Using traditional linear stability analysis one can infer whether these equilibrium states are stable (Figure 2c) or not (Figure 2a). Considerable importance is attached to whether the predator isocline intersects the rising or falling portion of the prey isocline. As mentioned earlier these techniques are only appropriate near equilibrium (May 24), and the presumed unstable conditions in fact generate stable limit cycles (Figure 2e). Moreover, it is unlikely that the predator isocline is a vertical one in the real world, since competition between predators at high predator densities would so interfere with the attack process that a larger number of prey would be required for stable predator populations. It is precisely this condition that was demonstrated by Griffiths & Holling (9) when they showed that a large number of species of parasites distribute their attacks contagiously. The result is a "squabbling predator behavior" (Rosenzweig 34,35) that decreases the efficiency of predation at high predator/prey rations. This converts an unstable system (Figure 2a) to a stable one (Figure 2c); it is likely that stability is the rule, rather than the exception, irrespective of where the two isoclines cross.

The empirical evidence described above shows that realistic fecundity and mortality (particularly predation) processes will generate forms that the theorists might tend to identify as special subsets of more general conditions. But it is just these special subsets that separate the real world from all possible ones, and these more realistic forms will modify the general conclusions of simpler theory. The ascending limb of the Allee-type fecundity curve will establish, through interaction with mortality, a minimum density below which prey will become extinct. This can at the same time establish an upper prey density above which prey will become extinct because the amplitude of prey fluctuations will eventually carry the population over the extinction threshold, as shown in the outer trajectory of Figure 2d. These conditions alone are sufficient to establish a domain of attraction, although the boundaries of this domain need not be closed. Within the domain the contagious attack by predators can produce a stable equilibrium or a stable node. Other behaviors of the mortality agents, however, could result in stable limit cycles.

More realistic forms of functional response change this pattern in degree only. For example, a negatively accelerated type of functional response would tend to make the domain of attraction somewhat smaller, and an S-shaped one larger. Limitations in the predator's numerical response and thresholds for reproduction of predators, similar to those for prey, could further change the form of the domain. Moreover, the behaviors that produce the sinuous reproduction curves of Figures 3c and 3e can add additional domains. The essential point, however, is that these systems are not globally stable but can have distinct domains of attraction. So long as the populations remain within one domain they have a consistent and regular form of behavior. If populations pass a boundary to the domain by chance or through intervention of man, then the behavior suddenly changes in much the way suggested from the field examples discussed earlier.

THE RANDOM WORLD

To this point, I have argued as if the world were completely deterministic. In fact, the behavior of ecological systems is profoundly affected by random events. It is important, therefore, to add another level of realism at this point to determine how the above arguments may be modified. Again, it is applied ecology that tends to supply the best information from field studies since it is only in such situations that data have been collected in a sufficiently intensive and extensive manner. As one example, for 28 years there has been a major and intensive study of the spruce budworm and its interaction with the spruce-fir forests of eastern Canada (Morris 27). There have been six outbreaks of the spruce budworm since the early 1700s (Baskerville 1) and between these outbreaks the budworm has been an exceedingly rare species. When the outbreaks occur there is a major destruction of balsam fir in all the mature forests, leaving only the less susceptible spruce, the nonsusceptible white birch, and a dense regeneration of fir and spruce. The more immature stands suffer less damage and more fir survives. Between outbreaks the young balsam grow, together with spruce and birch, to form dense stands in which the spruce and birch, in particular, suffer from crowding. This process evolves to produce stands of mature and overmature trees with fir a predominant feature.

This is a necessary, but not sufficient, condition for the appearance of an outbreak; outbreaks occur only when there is also a sequence of unusually dry years (Wellington 43). Until this sequence occurs, it is argued (Morris 27) that various natural enemies with limited numerical responses maintain the budworm populations around a low equilibrium. If a sequence of dry years occurs when there are mature stand of fir, the budworm populations rapidly increase and escape the control by predators and parasites. Their continued increase eventually causes enough tree mortality to force a collapse of the populations and the reinstatement of control around the lower equilibrium. The reproduction curves therefore would be similar to those in Figures 3c or 3e.

In brief, between outbreaks the fir tends to be favored in its competition with spruce and birch, whereas during an outbreak spruce and birch are favored because they are less susceptible to budworm attack. This interplay with the budworm thus maintains the spruce and birch which otherwise would be excluded through competition. The fir persists because of its regenerative powers and the interplay of forest growth rates and climatic conditions that determine the timing of budworm outbreaks.

This behavior could be viewed as a stable limit cycle with large amplitude, but it can be more accurately represented by a distinct domain of attraction determined by the interaction between budworm and its associated natural enemies, which is periodically exceeded through the chance consequence of climatic conditions. If we view the budworm only in relation to its associated predators and parasites we might argue that it is highly unstable in the sense that populations fluctuate widely. But these fluctuations are essential features that maintain persistence of the budworm, together with its natural enemies and its host and associated trees. By so fluctuating, successive generations of forests are replaced, assuring a continued food supply for future generations of budworm and the persistence of the system.

Until now I have avoided formal identification of different kinds of behavior of ecological systems. The more realistic situations like budworm, however, make it necessary to begin to give more formal definition to their behavior. It is useful to distinguish two kinds of behavior. One can be termed stability, which represents the ability of a system to return to an equilibrium state after a temporary disturbance; the more rapidly it returns and the less it fluctuates, the more stable it would be. But there is another property, termed resilience, that is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables. In this sense, the budworm forest community is highly unstable and it is because of this instability that it has an enormous resilience. I return to this view frequently throughout the remainder of this paper.

The influence of random events on systems with domains of attraction is found in aquatic systems as well. For example, pink salmon populations can become stabilized for several years at very different levels, the new levels being reached by sudden steps rather than by gradual transition (Neave 28). The explanation is very much the same as that proposed for the budworm, involving an interrelation between negative and positive feedback mortality of the kinds described in Figures 3d and 3f, and random effects unrelated to density. The same pattern has been described by Larkin (18) in his simulation model of the Adams River sockeye salmon. This particular run of salmon has been characterized by a regular four-year periodicity since 1922, with one large or dominant year, one small or subdominant, and two years with very small populations. The same explanation as described above has been proposed with the added reality of a lag. Essentially, during the dominant year limited numerical responses produce an inverse density-dependent response as in the descending of the mortality curves of Figure 3d and 3f. The abundance of the prey in that year is nevertheless sufficient to establish populations of predators that have a major impact on the three succeeding low years. Buffering of predation by the smolts of the dominant year accounts for the larger size of the subdominant. These effects have been simulated (Larkin 18), and when random influences are imposed in order to simulate climatic variations the system has a distinct probability of flipping into another stable configuration that is actually reproduced in nature by sockeye salmon runs in other rivers. When subdominant escapement reaches a critical level there is about an equal chance that it may become the same size as the dominant one or shrivel to a very small size.

Random events, of course, are not exclusively climatic. The impact of fires on terrestrial ecosystems is particularly illuminating (Cooper 3) and the periodic appearance of fires has played a decisive role in the persistence of grasslands as well as certain forest communities. As an example, the random perturbation caused by fires in Wisconsin forests (Loucks 21) has resulted in a sequence of transient changes that move forest communities from one domain of attraction to another. The apparent instability of this forest community is best viewed not as an unstable condition alone, but as one that produces a highly resilient system capable of repeating itself and persisting over time until a disturbance restarts the sequence.

In summary, these examples of the influence of random events upon natural systems further confirm the existence of domains of attraction. Most importantly they suggest that instability, in the sense of large fluctuations, may introduce a resilience and a capacity to persist. It points out the very different view of the world that can be obtained if we concentrate on the boundaries to the domain of attraction rather than on equilibrium states. Although the equilibrium-centered view is analytically more tractable, it does not always provide a realistic understanding of the systems' behavior. Moreover, if this perspective is used as the exclusive guide to the management activities of man, exactly the reverse behavior and result can be produced than is expected.

THE SPATIAL MOSAIC

To this point, I have proceeded in a series of steps to gradually add more and more reality. I started with self-contained closed systems, proceeded to a more detailed explanation of how ecological processes operate, and then considered the influence of random events, which introduced heterogeneity over time.

The final step is now to recognize that the natural world is not very homogeneous over space, as well, but consists of a mosaic of spatial elements with distinct biological, physical, and chemical characteristics that are linked by mechanisms of biological and physical transport. The role of spatial heterogeneity has not been well explored in ecology because of the enormous logistic difficulties. Its importance, however, was revealed in a classic experiment that involved the interaction between a predatory mite, its phytophagous mite prey, and the prey's food source (Huffaker et al 15). Briefly, in the relatively small enclosures used, when there was unimpeded movement throughout the experimental universe, the system was unstable and oscillations increased in amplitude. When barriers were introduced to impede dispersal between parts of the universe, however, the interaction persisted. Thus populations in one small locale that suffer chance extinctions could be reestablished by invasion from other populations having high numbers - a conclusion that is confirmed by Roff's mathematical analysis of spatial heterogeneity (32).

There is one study that has been largely neglected that is, in a sense, a much more realistic example of the effects of both temporal and spatial heterogeneity of a population in nature (Wellington 44,45). There is a peninsula on Vancouver Island in which the topography and climate combine to make a mosaic of favorable locales for the tent caterpillar. From year to year the size of these locales enlarges or contracts depending on climate; Wellington was able to use the easily observed changes in cloud patterns in any year to define these areas. The tent caterpillar, to add a further element of realism, has identifiable behavioral types that are determined not by genetics but by the nutritional history of the parents. These types represent a range from sluggish to very active, and the proportion of types affects the shape of the easily visible web the tent caterpillars spin. By combining these defined differences of behavior with observations on changing numbers, shape of webs, and changing cloud patterns, an elegant story of systems behavior emerges. In a favorable year locales that previously could not support tent caterpillars now can, and populations are established through invasion by the vigorous dispersers from other locales. In these new areas they tend to produce another generation with a high proportion of vigorous behavioral types. Because of their high dispersal behavior and the small area of the locale in relation to its periphery, they then tend to leave in greater numbers than they arrive. The result is a gradual increase in the proportion of more sluggish types to the point where the local population collapses.

But, although its fluctuations are considerable, even under the most unfavorable conditions there are always enclaves suitable for the insect. It is an example of a population with high fluctuations that can take advantage of transient periods of favorable conditions and that has, because of this variability, a high degree of resilience and capacity to persist.

A further embellishment has been added in a study of natural insect populations by Gilbert & Hughes (7). They combined an insightful field study of the interaction between aphids and their parasites with a simulation model, concentrating upon a specific locale and the events within it under different conditions of immigration from other locales. Again the important focus was upon persistence rather than degree of fluctuation. They found that specific features of the parasite-host interaction allowed the parasite to make full use of its aphid resources just short of driving the host to extinction. It is particularly intriguing that the parasite and its host were introduced into Australia from Europe and in the short period that the parasite has been present in Australia there have been dramatic changes in its developmental rate and fecundity. The other major difference between conditions in Europe and Australia is that the immigration rate of the host in England is considerably higher than in Australia. If the immigration rate in Australia increased to the English level, then, according to the model the parasite should increase its fecundity from the Australian level to the English to make the most of its opportunity short of extinction. This study provides, therefore, a remarkable example of a parasite and its host evolving together to permit persistence, and further confirms the importance of systems resilience as distinct from systems stability.

SYNTHESIS

Some Definitions

Traditionally, discussion and analysis of stability have essentially equated stability to systems behavior. In ecology, at least, this has caused confusion since, in mathematical analyses, stability has tended to assume definitions that relate to conditions very near equilibrium points. This is a simple convenience dictated by the enormous analytical difficulties of treating the behavior of nonlinear systems at some distance from equilibrium. On the other hand, more general treatments have touched on questions of persistence and the probability of extinction, defining these measures as aspects of stability as well. To avoid this confusion I propose that the behavior of ecological systems could well be defined by two distinct properties: Resilience and stability.

Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist. In this definition resilience is the property of the system and persistence or probability of extinction is the result. Stability, on the other hand, is the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns, and with the least fluctuation, the more stable it is. In this definition stability is the property of the system and the degree of fluctuation around specific states the result.

Resilience versus Stability

With these definitions in mind a system can be very resilient and still fluctuate greatly, i.e. have low stability. I have touched above on examples like the spruce budworm forest community in which the very fact of low stability seems to introduce high resilience. Nor are such cases isolated ones, as Watt (41) has shown in his analysis of thirty years of data collected for every major forest insect throughout Canada by the Insect Survey program of the Canada Department of the Environment. This statistical analysis shows that in those areas subjected to extreme climatic conditions the populations fluctuate widely but have a high capability of absorbing periodic extremes of fluctuation. They are, therefore, unstable using the restricted definition above, but highly resilient. In more benign, less variable climatic regions the populations are much less able to absorb chance climatic extremes even though the populations tend to be more constant. These situations show a high degree of stability and a lower resilience. The balance between resilience and stability is clearly a product of the evolutionary history of these systems in the face of the range of random fluctuations they have experienced.

In Slobodkin's terms (36) evolution is like a game, but a distinctive one in which the only payoff is to stay in the game. Therefore, a major strategy selected is not one maximizing either efficiency or a particular reward, but one which allows persistence by maintaining flexibility above all else. A population responds to any environmental change by the initiation of a series of physiological, behavioral, ecological, and genetic changes that restore its ability to respond to subsequent unpredictable environmental changes. Variability over space and time results in variability in numbers, and with this variability the population can simultaneously retain genetic and behavioral types that can maintain their existence in low populations together with others that can capitalize on chance opportunities for dramatic increase. The more homogeneous the environment in space and time, the more likely is the system to have low fluctuations and low resilience. It is not surprising, therefore, that the commercial fishery systems of the Great Lakes have provided a vivid example of the sensitivity of ecological systems to disruption by man, for they represent climatically buffered, fairly homogeneous and self-contained systems with relatively low variability and hence high stability and low resilience. Moreover, the goal of producing a maximum sustained yield may result in a more stable system of reduced resilience.

Nor is it surprising that however readily fish stocks in lakes can be driven to extinction, it has been extremely difficult to do the same to insect pests of man's crops. Pest systems are highly variable in space and time; as open systems they are much affected by dispersal and therefore have a high resilience. Similarly, some Arctic ecosystems thought of as fragile may be highly resilient, although unstable. Certainly this is not true for some subsystems in the Arctic, such as Arctic frozen soil, self-contained Arctic lakes, and cohesive social populations like caribou, but these might be exceptions to a general rule.

The notion of an interplay between resilience and stability might also resolve the conflicting views of the role of diversity and stability of ecological communities. Elton (5) and MacArthur (22) have argued cogently from empirical and theoretical points of view that stability is roughly proportional to the number of links between species in a trophic web. In essence, if there are a variety of trophic links the same flow of energy and nutrients will be maintained through alternate links when a species becomes rare. However, May's (23) recent mathematical analyses of models of a large number of interacting populations shows that this relation between increased diversity and stability is not a mathematical truism. He shows that randomly assembled complex systems are in general less stable, and never more stable, than less complex ones. He points out that ecological systems are likely to have evolved to a very small subset of all possible sets and that MacArthur's conclusions, therefore, might still apply in the real world. The definition of stability used, however, is the equilibrium-centered one. What May has shown is that complex systems might fluctuate more than less complex ones. But if there is more than one domain of attraction, then the increased variability could simply move the system from one domain to another. Also, the more species there are, the more equilibria there may be and, although numbers may thereby fluctuate considerably, the overall persistence might be enhanced. It would be useful to explore the possibility that instability in numbers can result in more diversity in species and in spatial patchiness, and hence in increased resilience.

Measurement

If there is a worthwhile distinction between resilience and stability it is important that both be measurable. In a theoretical world such measurements could be developed from the behavior of model systems in phase space. Just as it was useful to disaggregate the reproduction curves into their constituent components of mortality and fecundity, so it is useful to disaggregate the information in a phase plane. There are two components that are important: one that concerns the cyclic behavior and its frequency and amplitude, and one that concerns the configuration of forces caused by the positive and negative feedback relations.

To separate the two we need to imagine first the appearance of a phase space in which there are no such forces operating. This would produce a referent trajectory containing only the cyclic properties of the system. If the forces were operating, departure from this referent trajectory would be a measure of the intensity of the forces. The referent trajectories that would seem to be most useful would be the neutrally stable orbits of Figure 2b, for we can arbitrarily imagine these trajectories as moving on a flat plane. At least for more realistic models parameter values can be discovered that do generate neutrally stable orbits. In the complex predator-prey model of Holling (14), if a range of parameters are chosen to explore the effects of different degrees of contagion of attack, the interaction is unstable when attack is random and stable when it is contagious. We have recently shown that there is a critical level of contagion between these extremes that generates neutrally stable orbits. These orbits, then, have a certain frequency and amplitude and the departure of more realistic trajectories from these referent ones should allow the computation of the vector of forces. If these were integrated a potential field would be represented with peaks and valleys. If the whole potential field were a shallow bowl the system would be globally stable and all trajectories would spiral to the bottom of the bowl, the equilibrium point. But if, at a minimum, there were a lower extinction threshold for prey then, in effect, the bowl would have a slice taken out of one side, as suggested in Figure 4. Trajectories that initiated far up on the side of the bowl would have amplitude that would carry the trajectory over the slice cut out of it. Only those trajectories that just avoided the lowest point of the gap formed by the slice would spiral in to the bowl's bottom. If we termed the bowl the basin of attraction (Lewontin 20) then the domain of attraction would be determined by both the cyclic behavior and the configuration of forces. It would be confined to a smaller portion of the bottom of the bowl, and one edge would touch the bottom portion of the slice taken out of the basin. Figure 4 MSP 38.

This approach, then, suggests ways to measure relative amounts of resilience and stability. There are two resilience measures: Since resilience is concerned with probabilities of extinction, firstly, the overall area of the domain of attraction will in part determine whether chance shifts in state variables will move trajectories outside the domain. Secondly, the height

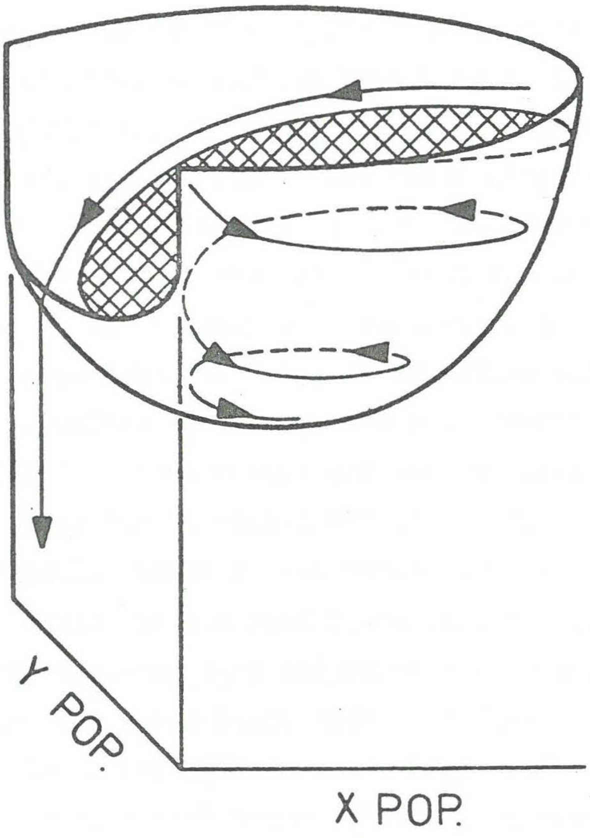

FIGURE 4. Diagramatic Representation Showing the Feedback Forces as a Potential Field Upon Which Trajectories Move. The shaded portion is the domain of attraction.

of the lowest point of the basin of attraction (e.g. the bottom of the slice described above) above equilibrium will be a measure of how much the forces have to be changed before all trajectories move to extinction of one or more of the state variables.

The measures of stability would be designed in just the opposite way from those that measure resilience. They would be centered on the equilibrium rather than on the boundary of the domain, and could be represented by a frequency distribution of the slopes of the potential field and by the velocity of the neutral orbits around the equilibrium.

But such measures require an immeanse amount of knowledge of a system and it is unlikely that we will often have all that is necessary. Gilbert & Hughes (16), however, have suggested a promising approach to measuring probabilities of extinction and hence of resilience. They were able to show in a stochastic model that the distribution of surviving population sizes at any given time does not differ significantly from a negative binomial. This of course is just a description, but it does provide a way to estimate the very small probability of zero, i.e. of extinction, from the observed mean and variance. The configuration of the potential and the cyclic behavior will determine the number and form of the domains of attraction, and these will in turn affect the parameter values of the negative binomial or of any other distribution function that seems appropriate. Changes in the zero class of the distribution, that is, in the probability of extinction, will be caused by these parameter values which can then be viewed as the relative measures of resilience. It will be important to explore this technique first with a number of theoretical models so that the appropriate distributions and their behavior can be identified. It will then be quite feasible, in the field, to sample populations in defined areas, apply the appropriate distribution, and use the parameter values as measures of the degree of resilience.

APPLICATION

The resilience and stability viewpoints of the behavior of ecological systems can yield very different approaches to the management of resources.

The stability view emphasizes the equilibrium, the maintenance of a predictable world, and the harvesting of nature's excess production with as little fluctuation as possible. The resilience view emphasizes domains of attraction and the need for persistence. But extinction is not purely a random event; it results from the interaction of random events with those deterministic forces that define the shape, size, and characteristics of the domain of attraction. The very approach, therefore, that assures a stable maximum sustained yield of a renewable resource might so change these deterministic conditions that the resilience is lost or reduced so that chance and rare event that previously could be absorbed can trigger a sudden dramatic change and loss of structural integrity of the system.

A management approach based on resilience, on the other hand, would emphasize the need to keep options open, the need to view events in a regional rather than a local context, and the need to emphasize heterogeneity. Flowing from this would be not the presumption of sufficient knowledge, but the recognition of our ignorance; not the assumption that future events are expected, but that they will be unexpected. The resilience framework can accommodate this shift of perspective, for it does not require a precise capacity to predict the future, but only a qualitative capacity to devise systems that can absorb and accommodate future events in whatever unexpected form they may take.

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APPENDIX IV

Where Resources and Environmental Simulation Models Are Going Wrong

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ABSTRACT

An experiment was conducted to assess and document interdisciplinary environmental modelling activities. Groups of modellers visiting each of eleven RANN projects were used to stimulate inter and intra project discussions of the process of modelling. Results indicated that the process is seldom recorded and the technology of interdisciplinary modelling has not been captured. Each new effort fails to maximize use of past experiences and three common issues are faced time and again (1) how to define and bound the model, (2) how to orchestrate the team to address the construction and validate the defined model, and (3) how to document and communicate the model or its results. A brief review of the modelling literature indicated these problems were identified in the 1950's in aero-space modelling efforts, yet the technology developed to address these issues has not been documented. There is a need to require clear, concise definition of any modelling activity prior to funding. It is difficult to construct a model given some specific boundaries and structure, and almost impossible, if these are lacking. A major incentive for documentation of the process as well as the substance of the model is required. In addition an accounting system that will provide a measure of the real cost of model development and use is needed.

INTRODUCTION

There is concern that many scientist/modellers have become reductionists; each problem is bounded, abstracted, and reduced until it can be analyzed by individuals skilled in particular disciplines. Such an approach to multidisciplinary problem analysis has at least two hazards that retard completion of the models. The first hazard is the failure of scientists to agree on the reduction process, the result being the neglect of important aspects of the problem because none of the reducers have scientific interest in that particular aspect, or the reduction includes identification of artificial problems to provide work for each scientist involved in the reduction process. The second hazard is the tendency for individual scientists assigned a part of the problem to model, to become enthralled with the science of the problem and lose sight of the original issue. An alternative pattern of model development is typified by the individual modeller who has attempted to broaden his knowledge and his ability to abstract information from primary and secondary sources and with heroic effort has single handedly created the equivalent of multidisciplinary models. Too often such individuals are so preoccupied with the development and construction of the models, that they do not document the theory, process, or operation. Whenever such people leave a project the models also disappear. Finally,most model builders are more interested in the construction than the utilization of models. Thus available models address problems that model builders perceive rather than problems that actually require solution. These perceptions of multidisciplinary modelling have spread throughout the community of funding agencies and there are pressures to reduce that support of modelling projects.

In response to these concerns, Dr. Philip Johnson, director of the Environmental Systems and Resources Division of the National Science Foundation initiated an experiment to stimulate modellers to develop a concensus of the actual status of multidisciplinary modelling and document their successful processes so others may learn from these experiences.

The experiment was to determine if a single individual (the author) given adequate resources could stimulate modellers to define their processes and discuss them with their peers. A group of 11 large RANN project (several hundred thousand dollar annual budgets, tens of researchers) concerned with environmental modelling were selected as a trial set for the experiment. The experimental procedures included group meetings with the investigators, crude Delphi surveys concerning the modelling processes, on site discussion in the presence of external peer modellers, and iterative reviews by the modellers of the documentation from these activities. During the construction of the experiment it was observed that it is extremely difficult to identify peer modellers, who are not NSF funded, and who could devote 5 to 10 days to a discussion of modelling processes during the Spring of 1973. Another observation was that the set of modellers were unaccustomed to discuss the modelling process.

PERCEPTION OF ENVIRONMENTAL MODELS

The process of structuring models for environmental systems is not well documented in the literature (Caswell et al., 1972). Many of the concepts of model development are derived from the analysis of physical systems (weapon systems, engineering works, deterministic systems) where well known procedures exist for modelling. These procedures have developed following a general pattern of explicit mental models, correlative models, and causal models (de Neufville and Stafford, 1971). The first step in the development of a model in any problem area is usually to construct models based on experience, intuition, and limited data to provide quantitative insights to the problem. The next step in the development is based on extensive quantitative data and empirical correlation of significant parameters. Such models can be used to forecast system behavior within the limits of observed data. The third step employs theory plus data and extensive validation to develop models that can predict system responses where the model is believed valid. In many physical sciences the process of model development has evolved over decades and theories and data are abundant to support each type of model development. In fact there are accepted forms of models to describe many physical systems. With such rich understanding, it is possible to abstract a physical system at many levels of resolution as the need arises.

Environmental modelling does not have such a rich history of model development. The attempts to construct models representing some portion of an environmental system encounter serious problems in the selection of the form of the model, the lack of a knowledge base to formulate mental models, the lack of data to construct correlative models, and the lack of data to substantiate causal models. Compounding this problem of model development is the fact that the nomenclature used to describe models, their characteristics, and their uses that exists in many disciplines is not consistent. For example, Shubik and Brewer (1972) define models as subroutines that are used in simulations, while Raser (1969) defines simulation as a type of model, and Meier, Newell and Pazer (1969) refer to simulation as the manipulation of models. Johnson, Newell, and Vergin (1972) describe a range of models from mental images to highly formalized mathematical models. Such differences in nomenclature impede effective transfer of the modelling process between engineers, ecologists, planners, management scientists, operation researchers, etc. who are each concerned with phases of environmental modelling. It is almost impossible for this report to avoid similar problems with model nomenclature and to prevent misinterpretation of this report.

There seems to be common agreement that the word "model" has been used in so many ways that it has lost any specific meaning. Each project and even individuals in a project attach different meaning to the word. While most people use the word "model" to refer to some representation of the real world, the form of this representation is highly variable. In most of the projects selected for this study the word model refers to quantitative representations that involve some form of computer manipulation to conduct an analysis. Some of the projects indicated that verbal and graphical representations or models were found to have greater utility in transferring the project output and in managing the projects than the computer based models. FOR THE PURPOSE OF THIS REPORT THE TERM MODEL IS USED TO DESCRIBE MODELS, SIMULATIONS, AND GAMES IN THE GENERAL DISCUSSIONS.

Based on the literature produced from these projects there is little indication that a large computer model or simulation that can respond to all environmental issues will be produced by these projects. Most of these projects have selected specific models for analysis and are focusing the given resources to address these models. In some cases the emphasis was on analysis rather than modelling. (Modelling is defined in this context as the explicit construction of an analytical framework for repeated analyses.) Models will be employed in these analyses, but the review of project reports was insufficient to identify the role of models.

Rather than attempt to classify models and analyze whether specific types of models are more effective than others, the negative response of most projects to the modelling issue redirected this study to examine the "process of analysis" employed by each project. Indirectly, the role of modelling in this process would hopefully emerge.

CONCERNS OF PREVIOUS ASSESSMENT OF MODELS

The concept of assessing large scale multidisciplinary modelling efforts is not novel nor recent. Non-military applications of modelling by specific disciplines or professions have been reported for the past two decades. Meyers (1972) effort to compile a continuing literature review of regional environmental models is one example. Cline (1961) analyzed the modelling process of over 50 large-scale weapon system modelling efforts in the early sixties. Models were classified as analytical (use of mathematical and/or statistical tools to derive closed functional forms), computer simulation (computer analysis with completely specified representation), man-machine simulation (manual specification of some representation) and game-simulation (computer used only for scoring). Over eighty percent of the models studied were computer simulation. The assessment was conducted by personal discussion with the principal investigators or analysis of model documentation. Two symptoms that were observed in that survey were (1) if a model was completed, documentation did not adequately represent the model and the sole ownership of this knowledge remained with the model builders; when they left the organization the model was essentially lost, and (2) if a model was under construction, the principal investigator usually had not completely formulated the model nor specified the analytical framework to be employed. The conclusion of the assessment was that models were poorly documented and information flow between similar efforts were poor. While some of the restriction of information flow was traced to security reasons, preoccupation of modellers with model construction and proprietary interests to attract continual funding were also dominant factors. Model builders had little incentive to document, since such action would reduce their monopoly to service or extend these models. The survey also revealed that persons responsible for model formulation had no basic theory that could be used to justify the method by which a variable is introduced into a model.

Shubik and Brewer (1972) recently conducted a similar but more ambitious assessment that resulted in not only an assessment, but also in a review of the literature on gaming and simulation as well as an index to and critical abstracts on gaming, simulation and model building. Shubik and Brewer surveyed 132 projects employing a seventy page questionnaire that required an average of 15 hours to complete. The projects were all under the sponsorship of the Defense Advanced Research Project Agency. One curious observation was that many research groups have maintained families of models for many years by separately proposing components of these models as discrete models to be funded, used, and evaluated independently. The optimum size of a module to be funded appears to be $200,000 to $300,000. Most research groups have found it is easier to sell the $200,000 to $300,000 components of a large model rather than to sell the large model for $400,000 to $600,000.

While the Shubik/Brewer questionnaire was more comprehensive and did not cite the previous efforts of Cline, the same types of questions concerning models were raised. The results of the questionnaire indicated that during the ten year period between assessments, the problems of poor documentation, low flow of information between model builders, and tendency for model builders to advocate selection of specific models rather than to employ a scientific basis had not improved and probably worsened. In addition the assessment indicated that models do not receive professional review nor are scientific standards of evaluation applied when models are examined. Furthermore large models have found little utility since shifts in personnel, poor documentation and communication, inadequate professional review, and poor conceptualization are exaggerated with larger models. Finally, the lack of cost information to construct, operate, improve and evaluate models is poor to nonexistent, thus no criteria exist to measure the effectiveness of proposed efforts.

In a separate study Brewer (1973) has found that the symptoms of military modelling efforts are also common to urban modelling efforts of HUD.

An unmentioned factor in military modellings is that the client had problems that required analysis and could describe his problem to some extent. In many environmental models the client is difficult to define and the sponsor of the research (RANN) desires not only the development of a model but the identification and transfer of the models to the client.

While these two surveys do not represent an exhaustive evaluation of large-scale modelling efforts, they suggest that major problems exist with the transfer of modelling science between large scale multidisciplinary projects. Another indication of the lack of communication of the modelling process is the emphasis on model results rather than on structure or construction in most scientific and professional literature. The collection of articles published by Patten (1971, 1972) contribute little to the effective transfer of environmental modelling processes to other disciplines, since most of these writings are too technical in nature for the novice.

A TEMPO study (NSF contract C-747) to develop assessment criteria for candidate RANN research programs employed several of the projects visited in this study as test "candidates". They identified the diffuse perceived need for environmental modelling technology, the lack of capability of the user to employ such technology, and the fragmentation of potential users as serious problems.

Environmental modelling has some parallels with corporate and economic system modelling. In both areas the focus is upon policy issues and decision making, and the problems typically involve interrelated physical, economic, and social factors. There is almost a void in scientific standards for selecting, evaluating, verifying and validating models. In their study of computer simulation modelling of business and economic systems, Meier, Newell, and Pazer (1969) found that there are few applications that could be called standard applications. Models are generally problem-specific, and bear little resemblance in subject matter or structure to prior models.

Very little research has been done on the organizational and administrative problems associated with interdisciplinary research programs in a university setting. One study was done for National Aeronautics and Space Administration by Kast, Rosenzweig, and Stockman (1970). They found that the university structure often makes interdisciplinary efforts difficult, and that there are many similarities between administration of interdisciplinary research and the program management form developed in government and private defense and space enterprises. Although one of the most critical decisions affecting success of interdisciplinary research is selection of the principal investigator and establishment of an effective mechanism for coordination, it appears that understanding of this role is not clearly understood either in the university or the sponsoring agencies.

In summary, even in the high technology arenas of defense and space, and the private sector where some degree of modelling success has been realized, modellers have not developed a broad scientific basis for modelling that has recognized standards for evaluating types of models, for selecting analytical frameworks, for documenting and transfering models, and for receiving or validating results. The problems encountered in modelling or analyzing environmental issues are further complicated by the lack of single well defined clients, or at least clients that can identify goals. Also the human and natural elements of the system to be modelled are much more complex than the man-made elements of a weapon system that are designed to have few objectives and to have known causal relations between elements. A critical step in the modelling of environmental systems will be the ability of the modeller to identify the frontiers of science in any given issue and not to propose applied modelling efforts that require many major advances in science to support the model.

SUMMARY OF OBSERVATIONS ON THE PROCESS MODELLING

The visits to each project focused the discussion on the process rather than substance of their modelling efforts. Most groups accustomed to site reviews for substance could not easily adjust to this new thrust. Only by repeated redirection could the discussion focus on how models are formulated, constructed, tested, employed, and transferred, and how the interdisciplinary research effort is organized and integrated. Those individuals steeped in modelling of physical systems or economic systems with accepted models considered much of the discussion trivial or irrelevant, while those individuals seeking to develop a theory for empirical basis for analysis could not respond to many of the modelling issues raised.

There appear to be three major issues that an environmental modelling effort must resolve if it is to be productive; (1) a clear definition of the system to be analyzed including a hierarchy of subsystems and components, plus a clear understanding of the status of theory, experience, intuition, and data that exists for each component, (2) an orchestration of individuals and management of project resources that can capture the knowledge of each system component in some form that can be integrated into an overall analysis employing some modelling process, and (3) the ability to document, transfer and apply the models or essence of the models to other modellers as well as potential clients. The following is a summary of the lies, myths, half truths, and truths collected in this experiment relative to these major issues.

ISSUE #1 - A CLEAR DEFINITION OF THE SYSTEM TO BE MODELLED AND PROPOSED USE OF THE MODELS IS REQUIRED INCLUDING A HIERARCHY OF SUBSYSTEMS, PLUS A CLEAR UNDERSTANDING OF THE STATUS OF THEORY, EXPERIENCE, INTUITION AND DATA FOR EACH COMPONENT IN THE SUBSYSTEM.

FORMULATION:

- The most difficult step in modelling is to formulate the proper framework for analysis.
- Selection of linear programming as a framework simplifies the problem of model construction and permits the major effort to focus on data development.
- The predominate modelling strategy is to decompose the problem into a set of subsystems, and further reduce each subsystem into its components until each component is recognized as a segment of some discipline that can be understood by an individual.
- Once all segments are understood by their respective disciplines, the pieces of the model can be integrated upward and the total model used for analysis.
- The decomposition strategy has a tendency not to address the primary issue, since "adequate understanding" is never achieved and models never are integrated.
- An alternative strategy to construct integrated models at the lower orders while developing new information at the next higher order has not been used, even though it would be a compromise between application and search for new knowledge.
- The strategy to construct models without data and then employ sensitivity analysis to identify critical components where research and new data would enhance model performance is not commonly practiced.

USE OF KNOWLEDGE:

- A weakness in most model development efforts is the failure to properly define the state of knowledge for each component of the system at any level. Lacking this definition a commitment is often made to a level of resolution that has too many components lacking information for construction. Thus, much effort is required to gather all information before modelling is possible. Models based on data that exists, but must be retrieved and analyzed are more likely to be completed than models that require experimental observations to supply the data. Models formulated to employ existing data should always be constructed prior to developing the next higher order model that requires new data.

VALIDATION:

- Models are sometimes considered to be validated when all components of the model are scientifically understood. Thus, the thrust to decompose a system until the components are small enough to analyze and resolve is very strong.
- A common theory of modelling concerning validation, sensitivity analysis, and standards for construction is minimal.
- Many modellers consider models validated when all variables they feel are important are included and none of the relationships between variables are incorrect by the modellers standards.

DIRECTIONS:

- General purpose models are less likely to be completed than models of specific situations. Models can be used to communicate, simulate (train) or predict.
- One school believes the decomposition will yield understanding that will permit construction of rich first order models, while another school contends the higher order models must be coupled directly to yield meaningful results.
- One model is claimed to be better than another when it has more variables, it handles more nonlinearities, when it is more precise, etc. The premium appears to be on proof by exhaustion rather than finese.

ISSUE #2 - AN ORCHESTRATION OF INDIVIDUALS AND MANAGEMENT OF PROJECT RESOURCES FOR MULTIDISCIPLINARY MODELLING EFFORTS.

CHARACTERISTICS OF TEAM MEMBERS:

- Most individuals have a biased view of any system that features their discipline and assume away the significance of factors considered by most other disciplines.
- Given a sector of a model to construct, individual scientists will prefer to explore the frontiers of this topic rather than develop an adequate representation to support the total model.
- An adequate reward and accountability system for faculty engaged in interdisciplinary work has not been devised by most universities and most faculty participate at the risk of professional advancement.
- The relationship between one model sector and all others is difficult to translate to the disciplines involved. This translation problem usually limits the feasible number of disciplines in a modelling effort to 2 or 3 direct participations. Introduction of more than this number requires each member to learn more than 2 or 3 discipline languages. Each additional discipline requires an additional year or so of team age. Thus, a team that is less than 3 years old cannot have effective direct input of more than a few disciplines while a ten year old team may have 5 or 6 direct discipline inputs.
- A team that has respect, plus a strong social interaction will have a higher chance for success than one that operates on only an employer/employee relationship.

CHARACTERISTICS OF TEAM LEADERS:

- Most modelling efforts require a strong personality that dominates the effort until the team can develop respect for each other.
- The principal investigator must be willing to devote a major proportion of his effort to management of the research project to create a research environment that encourages interaction among the project participants.
- In a university setting the more successful principal investigator is likely to be a senior faculty member who is well established in his discipline, and who has an interest in integrating the diverse activities required to accomplish the research goals. A principal investigator who is interested only in performing research himself will ignore development of an effective mechanism for coordination.
- The major function of an interdisciplinary modeller is to arbitrate disputes between disciplines and catalyze cooperative modelling efforts. The ability to pursuade and arbitrate are important.
- It may be necessary to have several leaders with differing characteristics to provide the necessary traits for management. Not only must a catalyst be present, but also someone who can synthesize and formulate.

- A project administrator (that relieves a principal investigator of management concerns) who lacks technical expertise and academic standing will probably not be effective in a university research environment.

MANAGEMENT PRACTICES:

- Concomitant with the need for a clear definition of the system to be analyzed is a need early in the project for organization of the work--task identification and task assignment. This is essential for subsequent integration of submodels.
- Formal control devices such as milestones, schedules, and goals are not widely used in projects observed.

ALTERNATIVES:

- An alternative method of supplying multi-disciplinary input is to abstract information from existing literature or authorities. While peer review or judgment is eliminated, this alternative does provide input without interdisciplinary communication problems. One problem is that individuals unfamiliar with a discipline may not properly abstract information to construct the model.
- Another alternative is to have one common discipline familiar to all individuals, thus each submodeller can translate to the common discipline to insure compatibility. Economics, system engineering, system ecology, and forestry have been used as common languages for modelling efforts.
- The concept that computer language or even a modelling language will integrate multidisciplinary teams has not been verified, most teams still employ verbal communication for a common basis. A new common language still appears to be a distant goal.
- Directions from funding agencies stimulate strong obedience by most projects. Some moderation in response would be healthy.

ISSUE #3 - THE ABILITY TO DOCUMENT, TRANSFER AND APPLY THE MODEL OR ESSENCE OF THE MODEL TO OTHER MODELLERS AND POTENTIAL CLIENTS.

DOCUMENTATION:

- A model contains so much information in such a compact language that most individuals feel it is easier to reconstruct a model rather than translate one. The understanding of someone else's model requires knowledge not only of the modelling language, but also the particular set of disciplines' nomenclature and philosophy.
- Even with minimum acceptable documentation, the majority of a model remains in the mind of the modeller. When the modeller leaves the model also leaves.
- Costs of model development and application are not recorded and no yardstick exists to determine "effective modelling efforts".

DOCUMENTORS:

- Most model builders have no incentive to document their products since they are primarily interested in model development.
- A separate group of individuals interested in model operation would be more inclined to develop proper documentation.
- Model transfer between modellers is apparently more difficult than transfer to clients.

TRANSFER AND APPLICATION:

- Models are only one tool employed in analysis and decision making. The model which performs functions similar to those currently used is most likely to be adopted. Models that require radical new skills of existing analysts will not be as readily accepted. Thus, models that primarily process data or focus on resource allocation problems are currently easier to transfer than simulation models.
- Transfer of models can be effectively achieved if users participate in construction.
  a. Users can participate by leaving the agency and pursuing an advanced degree while working on the team.
  b. Users can participate by residing with the team.
- It may be more useful to transfer the insight obtained through model construction.
  a. Books can be written.
  b. Testimony can be made on critical issues.
  c. Information can be supplied to advisory groups or key staff groups.
- Models can be used to educate through gaming forms of the model.
- The concept of constructing basic submodel modules that can be combined into many models has been advocated but seldom successfully developed.
- Currently, fragments of modellers or methods of modelling are in higher demand than the entire model. Graphic output routines, data preparation methods, subroutines are being transferred.
- Minimum elements of model documentation should include:
  a. Program listing.
  b. Variable listing, definitions.
  c. Flow charts.
  d. Program description (verbal).
  e. Operator's manual
  f. Programmer manual
  g. Documentation of model framework and theory
  h. Description of methods to reduce data to construct model.
  i. Cost data: construction, operation, maintenance.
  j. Identification of personnel involved in construction.
  k. History of review or validation by other peers.
  l. Record of users and outcome.

DISCUSSION OF OBSERVATIONS

While an entire book can be devoted to the expansion, analysis, and remedies for the observations summarized in the previous section, space restrictions prevent such an undertaking. Attached to this paper are proposed guidelines for proposals concerning modelling. These were derived from suggestions by Holling (1973) and discussions with various modellers visited in this experiment. The purpose of these guidelines is to force a clearer definition of the goals of large complex models prior to the commitment of major funds and to reduce the muddling model philosophy.

Since few of the projects visited could clearly define their models and preferred to argue that they are constructing general models the question of verification is difficult to discuss. Until such definition is made the issue of calibration and verification cannot be discussed with any meaning. It is recommended that standards for verification be identified as soon as comparable models are available. The use of sample problems in a "round-robin" of models could be useful in comparing or standardizing submodels of similar levels of precision. Unfortunately many model builders construct models that are not comparable, because they do not define their submodels adequately.

Since many projects seem to have unbalanced strength in submodel construction, an alternative funding pattern to develop balanced modelling efforts is to fund well defined submodel research where lack of adequate knowledge can be clearly demonstrated. Large scale model development should only be initiated <u>if a knowledge base is adequate</u> to support the degree of precision desired for the models and if the major modelling effort is the integration and abstraction of existing submodels. The major problem observed in the projects reviewed was the major diversion required to generate new basic data to support model development. Significantly less effort is required to locate existing data than to experimentally generate new data. Many projects gather all existing data prior to initiating the modelling process. Some experiments are required to define the necessary data required to support models of various precision.

The influence of the Management Science discipline in projects that include such individuals is observed to be highly positive. Previously, the need for an accounting system to evaluate the modelling process was noted. Such individuals are making efforts to develop such an account and provide a sense of management to the modelling process. These efforts should be encouraged and explicit direction given to establish these needed measures.

Many problems encountered in model development are related to disaggregation of data or information. This requires a compromise between data acquisition and processing costs and saving in model construction and validation costs. Since this debate has not been resolved, additional assessment of this issue is recommended.

It is premature to judge the documentation of these projects, but discussion indicates that little thought has been given to the style or content of any documentation. These observations confirm prior assessments and argue for firm criteria for model documentation.

While few if any of the projects visited could demonstrate a total model of the environment that is of concern, each project has developed some subcomponent that is unique and of use to other projects. If firmer goals for environmental modelling are not demanded, the only useful products from these projects will be the fragmented elements that other modellers identify and utilize. The stimulation of communication between projects was recognized prior to this assessment, but methods to implement communication are difficult. Several alternative actions by NSF could stimulate communication.

(1) Require that any newly funded project have the principal investigators spend several days at each of several existing projects to identify common areas of interaction.

(2) Identify major topics that are central to most regional environmental modelling efforts and fund semi-annual workshops to maintain interaction between researchers.

    land use models
    regional economics and allocation models
    water quality models
    air quality models
    waste generation coefficients
    public facility models

(3) Increased communication of new Ph.D.'s working in this field by holding special workshops for this group, since they appear to be the major forces in most modelling efforts.

Each interdisciplinary project funded must be considered another experiment in the management and organization of such efforts. Sufficient funds and resources must be allocated to analyze such experiments and contribute to the science of such activities.

In summary, the needs for standards for model definition in proposals, for demonstration of project orchestration and documentation, and standardized model subsectors for validation are answered by a series of recommendations. Since discussion of these recommendations by peer modellers would be healthy, it is further recommended that a task group be appointed to draft formal statements including examples that can be adopted as formal proposal specifications, and a sequence of funding increments that would increase the effectiveness of modelling efforts. Without these first steps toward standardizing model development, the fragmentation and abuse of modelling will continue.

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GUIDELINES FOR PREPARATION OF PROPOSALS CONCERNING MODELLING

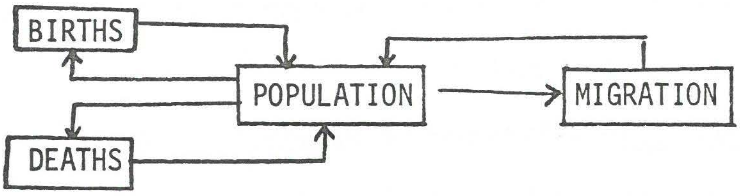
Brian W. Mar

Proposals that include major model development efforts must contain a clear and concise description of the proposed model(s). Proposals that fail to provide adequate detail on proposed model development will only be considered as candidates for short term exploratory grants and will not be considered for development into formal proposals appropriate for the RANN program. In addition to the narrative required for RANN proposals, requests for support of modelling efforts should also provide:

1. Definition of issues and variables - Identify the issues or questions that the model will be designed to address. For each issue or question identify those variables which will be internal to the model and those variables which will be generated as output or required as input. While it is acceptable to propose further research to adequately define relationships between variables being modelled, past experience has indicated that modelling efforts that have yet to identify the variables of interest are poor funding risks as RANN programs.
2. Flow Diagrams - Most major modelling efforts involve complex interaction between variables which are difficult to identify with only a list of variables. Frequently submodels are used to group variables that are highly related. Flow diagrams based on conventions used in control theory, cybernetics, and information theory have routinely been used to communicate these relationships. The simplest possible diagrams are preferred in the proposal to identify the relationship between the submodels, as well as the relationship between variables in each submodel. Since many

conventions exist for display of a flow diagram it is recommended that a key be provided identifying the significance of various arrows or various shaped boxes found in each diagram. The minimum diagrams included in a proposal are (1) relationship of all submodels in the overall model, and (2) relationship of significant variables in each major submodel. Notice that the flow diagram is a definition of relationships <u>not a computer programming flow chart</u> for logical computation.

3. <u>Interaction Matrices</u> - When proposed models are extremely complex with many submodels, variables, and interactions even flow diagrams can become too cumbersome. In such cases, an alternative form of presentation is suggested; for each variable included in the model, a statement is made defining the other variables which are affected by the variable under discussion. In matrix form this information can be presented by an identity matrix with rows and columns containing all the variables used in the model. The impact of one variable on another can be indicated by an "X" or other symbol in the appropriate row or column. For example a model relating births, deaths, population, and migration could be represented by a flow diagram as:



The equivalent interaction matrix would be displayed as

(Column)

(Row)

	BIRTHS	DEATHS	POPULATION	MIGRATION
BIRTHS, B			X	
DEATHS, D			X	
POPULATION, P	X	X		X
MIGRATION, M			X	

where the convention is used that a row entry impacts the column entry. Both the diagram and the matrix can be further translated to a mathematical form when the nature of the interaction is defined. In most proposals, the thrust of the research is to define and verify these interactions. Both the interaction matrices and the flow diagrams are mechanism to define for proposal reviewers what variables will be related in the model.

Given this explicit definition of the variables proposed for any model, reviewers of the proposal can assess the difficulty in developing the proposed relationships between variables. A discussion of background knowledge and sufficient literature citations should be included to demonstrate the feasibility of developing each proposed relationship defined in the interaction matrices.

4. <u>Degree of Precision Table</u> - In order to provide some measure of the proposed modelling effort, the proposal should list for each submodel, the design level of precision. This is a statement defining for each input and output variable the units that will be employed and the estimated acceptable

tolerance for data used in the models. For example, in the simple population model used earlier, defining the units for births as #/1000 population/census tract for a statewide model would require much more effort than #/1000 population/state. Also if order of magnitude values are acceptable, much less effort is required for validation that if a maximum of 1 percent errors in outputs are required.

The specification of the design level of precision permits reviewers to accurately evaluate if existing knowledge can support the level of modelling proposed and permits evaluation of the requested funding levels to accomplish the proposed modelling. An additional purpose of the degree of precision tables is to guarantee that individual components of the proposed models can eventually be integrated (dimensional and precision compatibility). In past modelling efforts excessive integration costs have been encountered when submodels were constructed independently without such definition.

While these requirements may appear stingent and redundant, the review of multidisciplinary modelling proposals cannot be effective without such data. Some reviewers will be familiar with flow diagrams, while others prefer matrices, tables, or lists. The presentation of the model definition in several formats will assist reviewers in the evaluation process. Explicit rather than implicit statement of the precision and boundaries of the models will promote clearer understanding of the proposed effort and the capability of the existing knowledge to support such efforts.

While it is recognized that these definitions specified for modelling proposals require substantial effort to develop, the cost of funding modelling projects that fail to provide such specific definition has been too high relative to their output. In the future, the definition of a plan for model development will not be funded as part of the model development, this plan must be formulated prior to major funding.

OPTION FOR PILOT STUDY

There may also be an interim funding phase between plan development and major funding where the project is requested to demonstrate the ability of the group to implement their plan. A six or twelve month pilot project could be authorized to conduct the first phase of model development. In order to facilitate this option, the proposal and plan should provide an iterative or evolutionary development of the models. One iteration or evaluation should be amenable for use in a pilot study, if this would become necessary. The purpose of the pilot study would be to demonstrate the orchestration of the team in model development and to sample the documentation and model transfer abilities of the team.

DESCRIPTION OF FINAL MODELS

In addition to the description of proposed model development, the proposed application and transfer of completed models must be described in the proposal. Upon completion of the project the following minimal elements of model documentation must be published

a) Description of the model including variable listings and definition, flow diagrams, interaction matrices, degree of precision table, and listing of relationships between variables

b) Program description if a computer model including listings and card deck or tape

c) Operator's manual including sample problem inputs and outputs

d) Programmer's manual explaining the maintenance and modification procedures, as well as the development of the program

e) Documentation of the theory and rationale for the model

f) Description of methods used to reduce data used in the construction of the model

g) Cost data for the construction, operation, and maintenance of the program(s)

h) Identification of personnel involved in model development, testing, and operation and their current address

i) History of review and validation by peers

j) Record of uses and outcomes of model application

The proposal should cite previous model documentation prepared by the proposing institution and indicate how these elements of documentation will be satisfied.

APPENDIX V

Problems of Scale and Detail in Ecological Modelling

David W. Goodall

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Problems of Scale and Detail in Ecological Modelling

D.W. Goodall

The continued existence and stability of ecosystems is closely bound up with niche structure. Though in the forms in which it is sometimes expressed it seems tautological, Gause's principle of niche separation lies right at the base of synecology. Species can coexist because their niches are not coincident. They do different things; or, if they do the same things, they do them at different times, in different places, or with differing response to the factors influencing them. If several species are identical in all their responses, all but one of them will go to the wall as a consequence of natural selection.

It follows that to try to account for or model the dynamics of an ecosystem without incorporating niche heterogeneity is highly hazardous. The special features of ecosystems, as against systems in other fields, stem from this heterogeneity, based on the laws of genetics and evolution which have only rather remote analogies in other types of systems. It is consequently to be expected that ignoring the niche structure of ecosystems will lead to gross over-simplification, and a failure to recognize what makes ecosystems different from other systems, both in their structure and behaviour.

Niche structure is made up of space and time, of processes and responses. In most ecosystems, spatial heterogeneity is intrinisc, and inseparable from their mode of functioning. Even in well-mixed planktonic systems, apparent spatial homogeneity is modified by the organisms themselves, for one not infrequently finds close spatial association of organisms from different groups in a symbiotic, commensal or parasitic relationship. To a parasite, the environment can never be spatially homogeneous so long as a host is present.

But in most ecosystems spatial heterogeneity is far more general and all-pervading. The abiotic environment initially provides heterogeneity on various scales--from the major physiographic feature down to minute soil-surface irregularities. And all these types of heterogeneity provide niche differentiation--from the distinction between the dominant trees of north-facing and south-facing slopes to that between the saxicolous lichens of rock surfaces and humicolous species in the spaces between them. As in the planktonic community, but more markedly because many of the spatial relationships are long-lasting, spatial heterogeneity is intensified or created by the organisms themselves. The fact that north-facing and south-facing slopes have a different tree cover means that conditions for a whole host of organisms--shrubs and herbs, fungi, birds, insects, and the rest--are still more different than the geomorphology and climate alone would have made them. Even in an originally homogeneous landscape, occasional shrubs--perhaps established at random--will constitute foci of biological activity of all sorts, so that the landscape for most other organisms is far from homogeneous. In the more severe deserts, areas away from the sparse perennial plants may be almost sterile of animals and microorganisms, which congregate under and around these primary producers. And places regularly occupied by one animal species--birds' nests, rodent burrows, termitaria--provide specially modified niches of which other animals and plants may take advantage.

Temporal heterogeneity is also important as a generator of niche diversity. That different species of animals are active at different times of day--some diurnal, some nocturnal, some crespuscular--is obvious even to the casual observer. These habits enable them to encounter different prey, predators or competitors, and to find different sets of abiotic conditions in which to pursue their activity. Similarly, in a seasonal climate, seasonal patterns of activity and reproduction differentiate niches. The hibernator and the species which continues active through the winter have adopted different strategies which, with appropriate concomitants, may both be viable in the same environment, so that this type of niche differentiation may enable them to coexist even though otherwise their requirements and responses may be very similar.

As with spatial heterogeneity, the fact that organisms respond to temporal heterogeneity increases the temporal heterogeneity of the environment for other organisms. It is unlikely that owls would have evolved the habit of nocturnal predation had a special class of suitable prey species not previously developed nocturnal patterns of activity.

A third way in which organisms may differ, and thus be enabled to coexist, is in the processes which they undergo or perform. A simple form of this differentiation is in trophic levels. A herbivore and a predator may be identical in their other characteristics and responses; this trophic distinction is fully enough to place them in separate niches. And the same is just as true, for instance, of microorganisms with different biochemical roles or activities--proteolysis and nitrogen fixation, say.

Finally, niche differentiation and species coexistence may depend on response differences. Two species may be doing the same things at the same time in the same places, but may still persist without one being exterminated so long as some of the processes in which they engage respond differently to the factors on which their rates depend. This seems likely to be the principal way in which the diversity of planktonic algal populations is maintained in a fluctuating environment: they differ in their responses to temperature, light, and nutrient availability, and thus are able to take advantage of thos periods of the seasonal cycle that happen to favour them over their competitors.

Having recognized the many-dimensioned diversity of ecosystem structure, and its importance for ecosystem dynamics, the would-be modeller is faced with the problem of how to include or represent this diversity in his models. If these models are to simulate in some sense--at some degree of resolution, with a certain precision--events in the real-world ecosystem, at least those parts of system diversity which are relevant to the particular events to be simulated need to be included in the model. If, for instance, one wishes to predict forage available for cattle, then it would be fatal if the model excluded processes involved in population explosions of an insect which defoliates the major forage species. If all insects or all herbivores are combined in the model, this effect will be lost.

Most ecosystem models developed so far have been very crude in this respect. The tendency has been to combine large numbers of biological elements, with widely differing responses and activities, into a single trophic level--or at best to divide them into a small number of broad groups--and to ignore a large part of the biological diversity of the system, as well as (usually) all the spatial diversity.

This tendency to extreme simplicity is certainly understandable. A model incorporating even a small proportion of the biological and spatial diversity of the system, and existing knowledge of the mechanisms involved, would be dismayingly large and complex. It would tax the capacity of existing computers, time requirements would be very demanding, and interpretation of the behaviour of the model would be fraught with difficulties. It seems that the future of ecosystem modelling may lie along some middle road, a road avoiding both the wilderness of simplistic irrelevance and the swamps of impracticable complexity.

Some of the most important problems resolve themselves into "lumping" vs. "splitting." To what extent should biological components of the system be divided? To what extent can they be combined without serious effects on the value of the model for the purpose in question?

These are not questions which can be answered a priori. They must probably be answered by exercising existing models. And it seems reasonable to start from the "splitting" end of the continuum of possible models. If one has a model incorporating a great deal of biological diversity, and proceeds to amalgamate groups of biological elements, then a comparative study of the performance of these models of diminishing resolution will show how important the biological diversity is for the performance sought. It is not to be expected that resolution will be equally important in different parts of the system--if indeed "equality" can here be given any useful meaning. In other words, one would need to test the effect of changing resolution in different biological (taxonomic or functional) groups within the system independently and in combination, rather than across the board.

Moreover, it should not be assumed that the same degree of resolution in a particular part of the system will be required for all the processes in which those organisms are involved. It may be, for instance, that large groups of insects may be "lumped" as far as their processes of assimilation, respiration and excretion are concerned, but that they must be kept separate to the specific level in respect of feeding habits and reproduction.

Detailed studies of a model of part of the system with high resolution may be used as a basis for replacing it with a different type of lower-resolution sub-model. One may, for instance, by exercising a high-resolution sub-model of nutrient uptake by roots, in which each plant species is included separately, be able to show that a reasonable arbitrary approximation may be possible in which species are not distinguished, though several soil horizons are included separately. While the high-resolution submodel incorporated actual mechanisms of nutrient uptake, including the concentration gradient across the root surface and the root respiration rate, the low-resolution alternative is more empirical, relating nutrient uptake simply to the temperature, water tension, and concentrations of nutrients and of root-tissue in the different soil horizons. The justification for replacing one submodel by the other, for a particular purpose, is then purely pragmatic: the low-resolution model gives results (input to the rest of the model) which are adequate to the purpose, within the range required. And the low-resolution model is, in a sense, a summary of the results of operating the high-resolution model within this range.

Another possible way of reducing the computation load imposed by biological diversity is to introduce it only during critical periods. To take a particularly obvious example, it may be possible to "lump" a large range of plants during the winter months--to assume that they are all behaving uniformly--but to "split" them and take account of their differing behaviour and response patterns during the summer months.

In some cases, instead of modelling a group of biological components individually, it may be possible to treat them as a diverse population, with known statistical properties--perhaps by a stochastic model. Instead of predicting that a particular insect larva in a particular year will reach epizootic proportions, the model might predict a probability that, in that year, some unnamed insect species of specified properties will reach epizootic numbers. Existing techniques for ecosystem modelling do not, however, handle parameters which are neither determinate, nor single samples from a known distribution, but cover simultaneously a range specifiable by a distribution. This methodological advance would be necessary before the suggestion above could be implemented.

Rather than "lumping" or "splitting" biological components, one may vary the resolution within a model in another fashion; in the time dimension. The time scales for different processes, or for different biological components, may differ widely, even by several orders of magnitude. Reproduction of vertebrates may often be treated on a time scale of a year, whereas their food consumption may require a time scale of a day. Some microorganisms may require time scales of an hour, while for earthworms a month may suffice. As with resolution among biological components, the appropriateness of different time scales of resolution for different processes should be tested by exercising models which incorporate the flexibility needed.

The same problem--though usually ignored--confronts the ecosystem modeller at a lower level. How is one to deal with sub-specific variation? In most groups of organisms, every individual differs to some extent from all others. To treat a species as internally homogeneous is to ignore differences which may be of importance in ecosystem functioning. And if these differences are taken into account, it will often happen that the average behaviour and response of the species will change in the course of time, as a result of selection on the micro-scale, which would most likely never lead to speciation, but may well have its influence on the dynamics of the system in which it is taking place.

Spatial heterogeneity is also important in ecosystem dynamics--not only in generating some of the niche differentiation on which biological diversity is founded, but also in determining the course of some of the processes in components of the system which are not differentially adapted to locally different condition. In the first place, heterogeneity in certain respects leads to accompanying heterogeneity in others--even at the abiotic level. Soil surface irregularities change the pattern of wind and water flow, and so may lead to localized deposition of mobile particles of different sizes, differences in rates of evaporation and water infiltration, and local temperature differences through (for instance) albedo changes.

Concurrently, these differences in abiotic conditions will lead to changes in the biota. Certain localities will meet better than others the requirements for particular species of plants, animals and microorganisms, and consequently the spatial distribution of all components of the system will become heterogeneous.

How does this affect ecosystem dynamics? In the first place, since almost all biological processes in a system are density-dependent--at least in the longer term--the average rate of a process will not be the same in a system where the biological components are patchily distributed as where the same components are homogeneously spread over the area. Then, many organisms may be able to make specific use of the spatial heterogeneity--may even require it as part of the habitat to which they are adapted. They may need different environments for feeding and for reproduction, different ones for night and day. Were the environment homogeneous, these species might not be able to survive. Consequently, the development of heterogeneity changes the species complement of the ecosystem, not only by providing single specialized niches for some species, but by providing the actual range of different environment which may for others constitute part of the niche specification.

Vertical heterogeneity is at least as important as horizontal. Even in a planktonic system, there is often some stratification with respect to temperature and solutes, and inevitably with respect to illumination. In a benthic community, and even more in a terrestrial community, the vertical differentiation affects more characteristcs and is reasonably constant through time, and hence more important.

A terrestrial plant community usually has a structured canopy, providing a range of environments for other organisms. And, within the soil, conditions in successive horizons are very different--for root growth, for soil animals, and for the microflora.

In the spatial differentiation of ecosystems--horizontal and vertical--there are numerous discontinuities. Some of these are absolute, but more are partial, consisting of a zone of much more rapid change separating two zones which are relatively homogeneous. This means that the partial differential approach, which has had considerable success in modelling problems of meteorology and physical oceanography, is not well suited to modelling spatially heterogeneous ecosystems.

Many ecosystem modellers have avoided facing this rather challenging problem. The question of vertical heterogeneity has not infrequently been approached by dividing the ecosystem, above and below the soil surface, into a number of discrete compartments, transfers across the boundaries being handled by difference equations. This is reasonably practicable, since the number of such compartments is often quite manageable--of the order of ten, say. But the same approach cannot be applied as easily to horizontal heterogeneity. But the same approach cannot be applied as easily to horizontal heterogeneity.

Some ecosystem modelling projects have distinguished compartments in the horizontal plane--for instance, in connexion with drainage patterns and their concomitants for plants and animals. It is then assumed that each of these compartments can be treated as internally homogeneous, with fluxes taking place across the boundaries. But this is appropriate only for rather large-scale heterogeneity; and in ecosystems, as has already been pointed out, one has several nested scales of heterogeneity, none of which may safely be ignored in its possible influence on ecosystem dynamics.

Much horizontal heterogeneity takes the form of a mosaic pattern, with the same type of element recurring repeatedly, though the class of similar elements is subject to considerable variation in composition, size, and shape. This suggests that it might be possible to treat the ecosystem as composed of a limited number of populations of patches, each of which populations could be defined by statistical distributions of their biological and abiotic characteristics, as well as their size, shape, and peripheral relations with patches of other types. Again, the problems of handling dynamic relations in a system specified by a set of distributions rather than a defined set of values would arise. And there would be further problems associated with the boundaries between patches of different types.

As with biological diversity, so with spatial heterogeneity, the problem poses itself: "How much does it matter? Is it really going to affect the dynamics of the system, for the particular purposes in question?" No answer can be given *a priori*. One must try. If one has a model in existence incorporating, as realistically as possible, the main features of spatial diversity, one can then modify it by removing these features one by one, or all together, and see how much effect it has on those aspects of behaviour of the whole system which are currently of interest. By eliminating spatial heterogeneity from the model, and treating the system as homogeneous (but with parameters selected to correspond with the known pattern of heterogeneity), can one approximate sufficiently closely, in a variety of circumstances, the results obtained with the more complex model? If so, then one may accept the simpler approximation.

Throughout this presentation there has run the theme: though diversity is inherent and important in ecosystem structure and function, for practical modelling purposes we must perforce simplify. What simplification is permissible and acceptable depends on a definition of goals--definition in terms of what predictions are needed, and with what precision. The answers may differ enormously, and a model satisfacory for one purpose may be quite inadequate for another.

There are essentially two ways in which proposed simplifications may be tested. One--and probably the most satisfying--is against actual field observations. Validation in this sense has been discussed at length elsewhere (Goodall 1972). Again, objectives must be clearly defined, not only in terms of predictions and their precision, but also in terms of the universe of systems to which the prediction capacity should apply. It will rarely be intended that the prediction should apply to a single ecosystem, and probably never only to one ecosystem in a particular period of time, with its specific meteorological and other inputs. The particular ecosystem, and the particular time period, are to be regarded as representative samples of a wide range of conditions to which the model is intended to apply. Consequently, field observations to validate the model, and to provide evidence on the acceptability of proposed simplifications, should constitute a sample covering this whole range of systems--a weighted sample, perhaps, if different parts of the range are not of equal interest.

This is probably the ideal method of testing proposed simplifications of the model. But it is clearly very laborious. The alternative--somewhat less satisfying, but much more practicable--is to use models which incorporate the best available biological knowledge of the system in all its detail as a surrogate for the actual real-world system, and adopt the simplified models in so far as they do not deviate unacceptably from this more complex basis for comparison.

The comparisons need not necessarily involve models of the whole system at all stages. Deviations in sub-system output could be tested **first**, for instance, and then the effect of such deviations in input to the rest of the system could be examined without actually incorporating the two alternative subsystem models. And, as suggested above, it may often be possible to use sub-models "off-line," so to speak, to generate inputs for a whole-system model which would then be effectively simplified in that respect.

It should be emphasised again, however, that these alternatives to direct validation imply an existing model, or set of models, incorporating the most detailed biological knowledge of the system that can be assembled. And this in turn implies an expansion of ecological knowledge, for anyone who has tried to build such a model is aware that the gaps in existing knowledge are enormous. No efforts by modellers can compensate for these gaps. They must be filled by direct biological studies.

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APPENDIX VI

Controlled Ecosystem Pollution Experiment (CEPEX)

J.H. Steele

Controlled Ecosystem Pollution Experiment
(CEPEX)

J.H. Steele

Introduction

CEPEX is a cooperative research plan to study the effects of pollutants on the marine environment. It involves laboratories in the U.S., Canada and the U.K. and is part of the International Decade of Ocean Exploration. The scientific leader of the programme is Dr. David Menzel of Skiddaway Institute of Oceanography, Savannah, Georgia, U.S.A.

The plan is based on the primary tenet that the important and long-term effects of pollution are those which influence the stability of marine populations. This requires that the study include: (1) a basic understanding of a natural or controlled experimental ecosystem with the ability to predict normal fluctuations in the former or to compare control and perturbated systems in the latter, (2) laboratory and field studies of the effect of pollutants in their environmental form, (3) ecosystem surveillance studies of the concentrations of these same chemicals within all trophic compartments of the system, (4) simulation models of the energy fluxes and effects of pollutants within the marine food chain, and (5) most importantly, field validation studies involving the manipulation of test ecosystems.

In dealing with natural marine ecosystems having unknown or variable boundaries (such as any given oceanic area) the rates of input, flux and loss from the system must be considered on three dimensional axes. Given estimates of these parameters the effects of pollutants in a multi-compartmental, often transient food chain must be predictable. To acheive these results, it is necessary to understand hydrography in terms of both vertical and horizontal advection and eddy diffusion. Estimates of standing crops, production rates, population fluctuations, migrations and species interdependence (food chains) are also required and must be predictable. Such a comprehensive study is at present considered unfeasible in "open marine" systems for the following reasons:

(1) Accurate estimates of biomass are contingent upon being able to quantify the effects of patchiness and uneven population distribution. This would require a major collection, assessment program over an area of at least 50 x 50 km and in the open ocean to a depth of at least 2000 m. At present it is

difficult to quantify and separate temporal and spatial variability from normal random unevenness in distribution except by elaborate collection and statistical techniques. To obtain usable "base line" information on population structure in the ocean it is estimated that a continuous record of 10 years is required. Thus, it is suggested that unless events lead to catastrophic decline the net effect on populations will not be easily ascertained on a "real time" basis.

(2) Excepting phytoplankton and in some cases fish (the latter where fisheries statistics are available) the natural growth rates and production (turnover time) of organisms cannot be determined. This applies most critically to the zooplankton, which are likely to be the most sensitive component of the food chain.

(3) It is currently not possible to quantify properly the upper trophic levels of the food chain or to determine if the presence of larger predators is transient or permanent in the confines of the area under study.

(4) If population alterations are detected, it may not be possible to determine if the cause is climatic, due to fishing pressure, a normal population fluctuation, or is due to pollution.

(5) If the above objections can be overcome an overriding limitation is that "open systems" cannot be experimentally manipulated.

One solution is to downgrade the "open ocean-complete ecosystem" approach to pollution effects studies and to initially restrict the program to an environment that can be properly managed, experimentally manipulated and which is sufficiently like the "real world" to provide field validation studies for simulation models.

The characteristics of such controlled ecosystems should be:

(1) Two or more trophic levels need to be used with more than one species at each trophic level. Many of the most significant effects are likely to arise from changes in competition for nutrients, food selection and other "natural" processes which determine ecosystem stability.

(2) The volume of the enclosed water must be capable of supporting populations at their natural levels (without concentration) for at least 30 days and optimally 100+ days so that deviations from normal production and decomposition processes can be studied. The life cycle of a copepod is 30-90 days. The time from egg to juvenile of many fish species is in the same order of time.

(3) Ability to perturbate the system. Since the aim of this study is to observe the effects of different pollutants it is necessary not only to be able to introduce pollutants into the system at realistic levels but to have replication of controls and of the pollutant. Thus, 4 to 8 or more controlled environmental enclosures are required.

(4) Verification of computer simulations. If a model can simulate the results obtained in the experimental ecosystems proposed here then the reliability of the model for predicting the consequences of pollution in other areas will be greatly increased. This capability is particularly necessary for predictions of effects in the open ocean.

Thus the program for CEPEX contains observational, experimental and theoretical components. Only the proposed plan for modelling is given here.

Modeling in plastic enclosures

In models concerned with transfer, particular pollutants are used as variables in determining rates of movement between large "blocks" of a natural system. When effects on the ecosystem are being considered, pollutants are not introduced directly as parameters. It is the effect of the pollutant, such as a change in growth rate of a particular zooplankton, which is the input to the model and the output is the consequence to the rest of the system. Thus, discussion of the theoretical aspects is, essentially, a consideration of the problems in defining and then quantifying the basic ecological parameters.

Our first assumption is that simple Volterra type models are insufficient when considering those factors which induce stability in ecosystems. More complex models are required and these added complexities can be of three types:

(1) Physical: e.g. the effects of lateral diffusion and vertical stratification and their relation to the known "patchiness" of phyto- and zooplankton.

(2) Population diversity: It is possible that species diversity may be a necessary factor in producing dynamic stability in ecosystems although theoretical work (Steele, in press) shows that, by itself, it is not sufficient to remove the inherent instabilities of simple models.

(3) Behavior: The feeding and breeding responses of zooplankton may be much more complex than the functional relations used in simple models. It has been shown (Steele, 1972) that the introduction of threshold feeding responses of zooplankton, for which there is experimental evidence, can produce "realistic"

outputs from a model.

The introduction of these complexities presents two difficulties, one technical and one biological. The step-by-step computer solution of a set of equations using numerical methods is relatively straightforward when there is only one independent variable; for example, when nutrient concentration (N), phytoplankton (P) and zooplankton (Z) densities are functions of time only. When a model also contains a space variable (e.g. either horizontal, x, or vertical, z, distance) there are technical problems concerning the size of increments, $^{\delta}x$, $^{\delta}z$, $^{\delta}t$ that can be used. In particular there is usually a condition that $^{\delta}t$ has to be small relative to the size of the space increments $^{\delta}x$ or $^{\delta}z$. In a simple "time" model the increments may need to be fractions of an hour. Thus the introduction of a space variable not merely adds its own complexity but can increase the computing time required by several orders of magnitude. For this reason space-time models tend to be as simple as possible in other aspects. The upwelling model of Walsh and Dugdale (1971) has "boxes" to represent compartments between which there is lateral exchange, herbivores are considered only as nutrient excretors and the emphasis is on the nutrient-phytoplankton interactions over a five-day period in the downstream flow of an upwelling plume. The expected distribution in the plume was determined by starting from conditions at the initiation of upwelling and running the model for 10 days with time increments of 1 hour. Vinogradov et. al.(1972) looked at vertical profiles of nutrients, bacteria, phytoplankton and zooplankton from an upwelling area taking account of vertical stratification but ignoring lateral mixing. Their model ran for 60 days to show the vertical changes that could occur as the water mass moved away from the upwelling area. They obtained general agreement with observation, particularly in the mid-water chlorophyll maxima but give no details of the computing methods. Again, zooplankton are considered in terms of biomass rather than as numbers of individuals growing and reproducing. Further, their work illustrates the major defect of such biologically simple models in that there is no evidence of the system coming to a steady state. It is the conditions for maintenance of a longer term "steady state" which are the main concern of models relating to large scale low level pollution. It seems likely that this requires more realistic representation of plant and animal populations.

The biological problems concern the introduction of more than one species of phytoplankton or zooplankton. Theoretically this means having more than one type of response at each trophic level, e.g. varying nutrient kinetic curves for different parts of the phytoplankton population, different grazing characteristics for zooplankton feeding on these phytoplankton groups, a range of sizes for adult zooplankton, etc. Theoretically we have some concept of how this could be done (Steele, in press), at least for two size groups of phyto- and zooplankton. The problem is that, although we have information on, say, kinetics of natural phytoplankton as a single group in relation to nutrient concentration, we are hardly yet in a position to separate these into a large number of categories. It is possible that some separation could be made on the basis of size of cell (Eppley, pers. comm.). Similarly, herbivore grazing may be expressible as a function of cell size but the actual form of the functional relation is not yet known.

Given these various problems, it is not practical to set up immediately a model combining (1) spatial and temporal processes, (2) species diversity and (3) complex functional responses of individuals. The basic assumption in this approach to the effects of pollutants on ecosystems is that these must be studied over relatively long periods and by examination of the more subtle responses at herbivore and primary carnivore levels. Thus, for this aspect, the model should concentrate on details of metabolic, behavioral and reproductive processes, including some simple "diversity". The modeling of physical processes should be as simple as possible but some separate or sub-model of vertical processes affecting phytoplankton should be investigated, possibly along the lines of the simple mathematical model of Steele & Yentsch (1960) which has some support from field observations (e.g. Kiefer et. al., 1972). On this basis the experimental counterpart of the theoretical model is an enclosed, well mixed, body of water containing phytoplankton, more than one, but not too many, herbivores, with carnivores as an optional extra.

This gives the theoretical background to the development of large plastic enclosures (CEE) for experimental work in sheltered sea areas. The first test in CEE is whether lateral spatial heterogeneity can be removed and the system still operate in a reasonably realistic manner with the horizontal dimension of 0.01 km rather than 10-100 km which is order of "patches" in the sea. The first and simplest trial concerns the nutrient and carbon budgets. Fig. 1a illustrates short term nutrient flow in the upper layers where the zooplankton nutrient (Z) is partitioned between excretion (E_1), faeces (F) and predators (C). The carnivores, such as young fish, in turn excrete nutrient (E_2) but their growth is lost to the system over the time periods considered (100)days). At the same time nutrients are mixed up from deeper water (M). Two possible CEE units are indicated, one with - one without predators. Some hypothetical numerical proportions are given in Fig. 1b. The simplest CEE unit to use is that without predators, but in that case two factors must be considered. The faecal material will sink to the bottom of the bag. Either it remains there and decomposes, or it is removed at fairly frequent intervals. The latter is

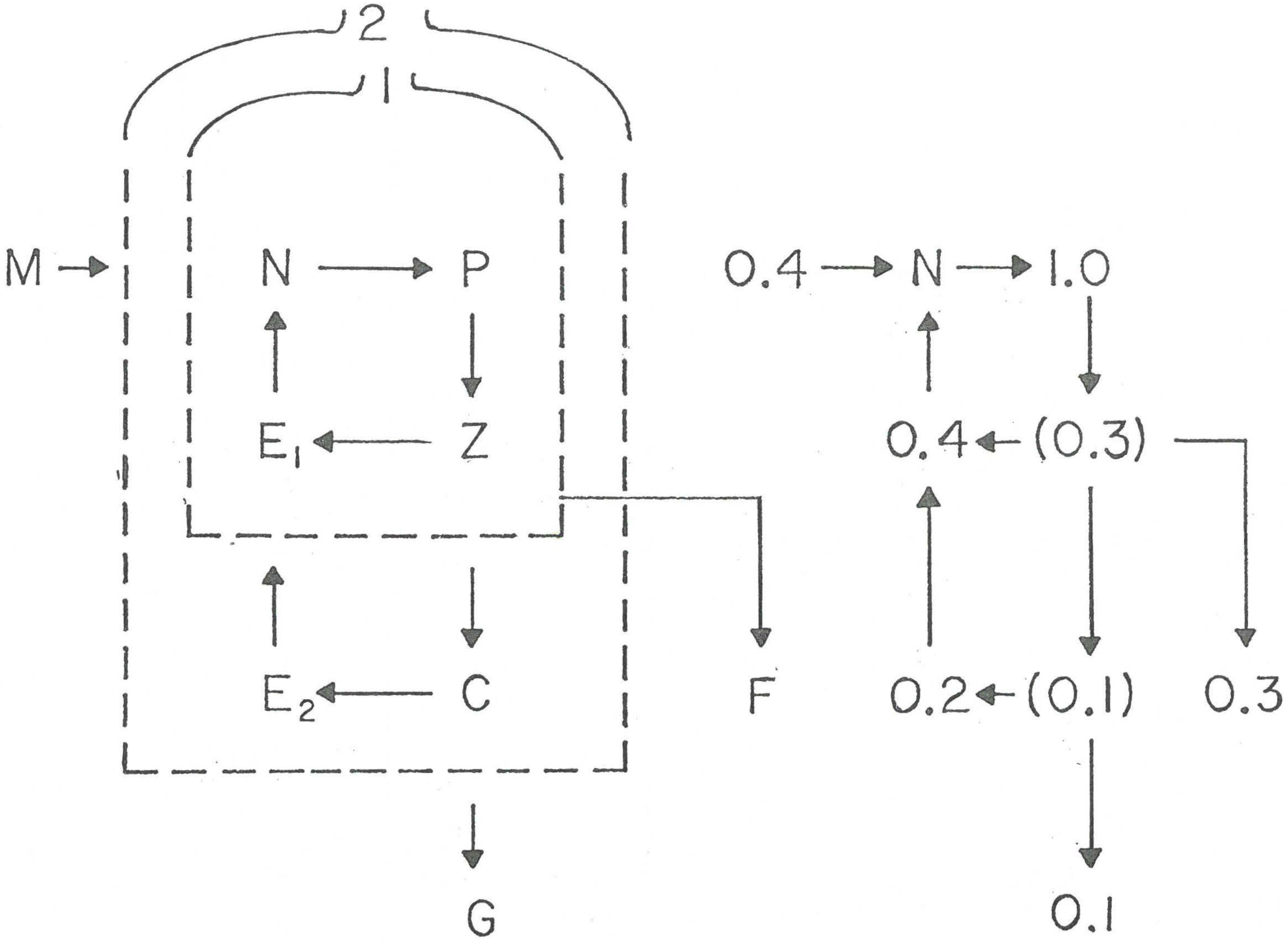

Fig. 1. A very simple nutrient (N) flow model for plants (P), herbivores (Z) and carnivores (C). F = particulate faecal material; E_1,E_2 = soluble nutrient excretion; G = carnivore growth removed from the system. M = nutrients resupplied by mixing (or by regeneration from the bottom).

preferable since (1) in the sea it falls out of the surface system, (2) we wish to measure this rate and also, with pollutants, to know this transfer from the pelagic to the benthic system. However, if this is removed, nutrients must be reintroduced. The most natural way to do this is by removing some nutrient poor water from the bag and replacing it with nutrient rich deep water. The second factor in this simple CEE is that there is no predation on the herbivores. This can be simulated by filtering daily a percentage of the water to remove the copepods. (The exchange of water will perform, at least part, of the same function.) This also removes the nutrients in the plankton which would have been returned to the water by the excretion of the predators. Thus some nutrients (esp. NH_4) may need to be added to the water.

Within each CEE there can still be vertical stratification giving very marked vertical gradients in chlorophyll. It is possible that this spatial heterogeneity is important to the herbivores who may concentrate for feeding in the maxima. However, these gradients would introduce a spatial dimension in the model with the resulting difficulties already described. This may have to be eliminated theoretically by averaging over the vertical dimension. Experimentally, mixing of the whole or a large upper part of the column would provide a better comparison. Thus a further initial experiment should compare a mixed and unmixed column. It seems easiest to start without carnivores in each case but it is possible that the carnivores could be cleverer than a plankton net.

During these initial experiments, measurements would be made of carbon and nitrogen transfer rates within and outside the two CEE units. This could provide the test for a simple input-output (I/O) model. Measurements of phytoplankton production by C^{14}, and experiments on zooplankton grazing rates would estimate internal transfers and also would provide a test of theoretical formulae for these factors which are essential components of the model. These experiments would provide (a) experimental evidence of the adequacy of the bags as a simulation of the environment outside, (b) tests of the adequacy of a model based on single categories of "phytoplankton" and "zooplankton". A food chain (F/C) model of this type is already available in a general form (Steele, 1972) and Fig. 2 illustrates the type of output. This model ignores effects which operate differently on different species within a given trophic level; also it ignores factors other than food which may affect reproduction. It could handle effects such as a general change in photosynthetic rate or a general decrease in feeding rate of all copepods present. Where it has been shown from laboratory experiments that a pollutant can have such an effect, then the model would predict the consequences for the general plant and herbivore populations in the CEE and this could be tested. This is one way in which an immediate use

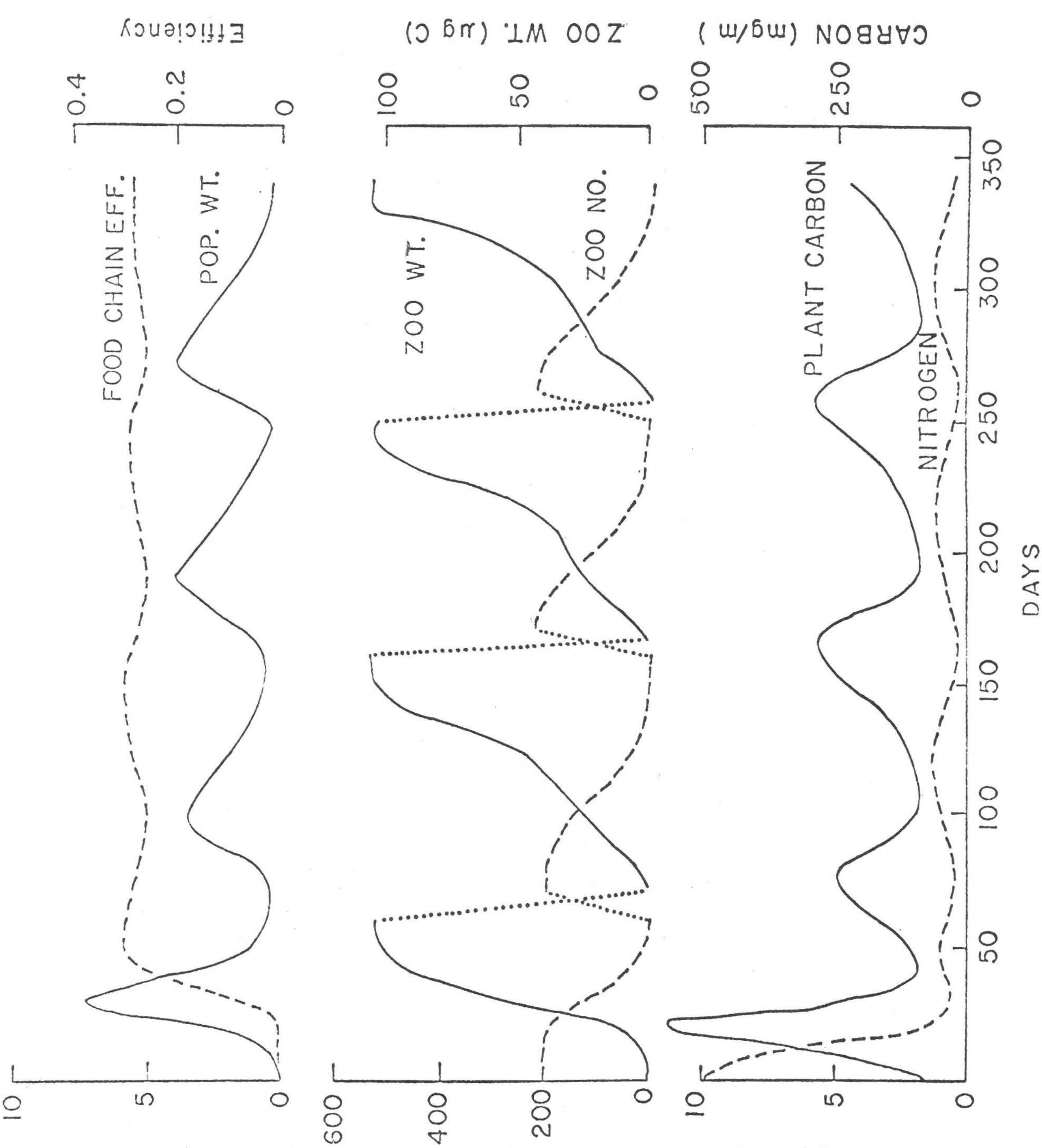

Fig. 2. Output from a food chain model simulating a spring outburst and subsequent events.

could be made of the model in relation to pollution.

However, the real use of CEE is to study the effects on mixed populations including factors affecting reproduction. To understand what is happening in such an experiment and to provide basic information for the construction of a better model, certain types of data are required which are not presently available; on the growth rate of individual phytoplankton species; on the grazing rates of different species of copepod as a function of their own size and the species composition and density of their food organisms; on copepod reproduction as a function of factors other than food intake and the causes of mortality of eggs and early naupliar stages. A simplifying assumption for which there is some evidence is that phytoplankton growth and zooplankton grazing are functions of phytoplankton cell volume, i.e. that actual species composition can be ignored. This brings the problems of measurement within the scope of equipment such as particle volume counters.

The first stage in development of a food web (F/W) model would be the running of a 2-plant/2-herbivore system. This would be used to explore the problems of interactions within trophic levels. Beyond this further development would depend on the results coming from the bags and from the concurrent laboratory experiments. As a starting point a simple analytical model is available which shows how small changes in parameters can produce unstable oscillations or eliminate species from the assembly (Steele, in press).

A simple diagram of the possible sequence of CEE experiments and the relation to modeling is given in Fig. 3. It illustrates the problem of an excess of choices starting from a simple plant-herbivore association with the addition of various carnivores, a range of pollutants or both. The organizing of the sequence of experiments will require considerable thought. The squares represent stages in complexity of experiment within the bags but the separation into different "experiments" is arbitrary since, for example, some "F/C" measurements would be made at the I/O stage.

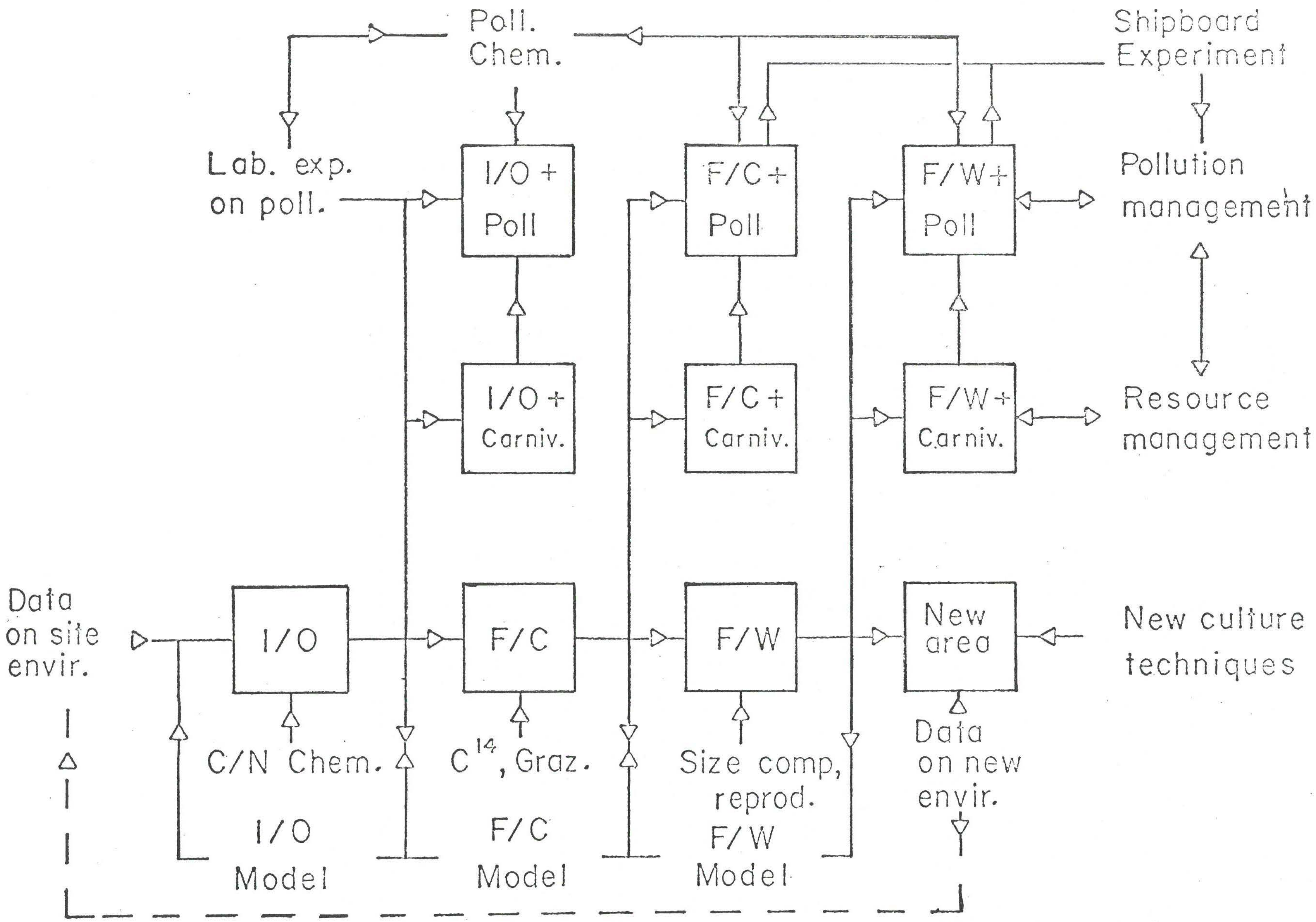

Fig. 3. The possible development of experiments within CEE indicating the options and the relation with laboratory work and simulation modeling.

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APPENDIX VII

An Interdisciplinary Approach to Development of Watershed Simulation Models

Carl Walters

AN INTERDISCIPLINARY APPROACH TO DEVELOPMENT OF WATERSHED SIMULATION MODELS

Carl Walters

SUMMARY

A workshop approach for the rapid development of simulation models is described. The key feature of the approach is intimate involvement of resource specialists in the model building process, so that communication between resource disciplines is greatly enhanced. Two watershed models that have been developed in one-week workshop meetings are described to show the kinds of factors that can be considered. One model is concerned with small coastal watersheds in the Pacific Northwest, and the other deals with part of the James Bay Area, Quebec. Both of these models have helped scientists of Environment Canada identify major information needs that are not being considered in current research and management programs; in particular, little is known about the dynamics of recreational demand.

INTRODUCTION

Hydrologic simulation models are now widely applied for investigation of short and long term water flow patterns in watershed systems. However, there is a need to see if such models can be connected to biological and economic predictions to provide a comprehensive picture of the watershed as a management unit. Considering present knowledge of ecological interactions in watersheds, it would be unreasonable to expect any comprehensive model to have high predictive power. However, a major problem in watershed management is to ensure communication between the research and management disciplines (e.g. forestry and fisheries) that are responsible for various phases of programme development. Too often we find watershed investigations conducted as a series of fragmentary studies that have little relevance to one another. The exercise of developing a simulation model, by providing a common language and concrete focus for discussion, can provide specialists with a unique opportunity to present their mutual information needs clearly and precisely. For example, the fisheries biologist cannot be content with a vague statement about his need for water flow data; he must instead show exactly what numbers, in terms of spatial and temporal resolution, can be used in his fisheries predictions.

Almost always the exercise of model building suggests major information needs that would not otherwise be recognized, both at the interface between disciplines and within particular areas of study. It is only after some preliminary but intensive modelling work has identified these information gaps that we can expect the kind of data to be collected that will eventually lead to useful predictive models. It is usually supposed that data collection must precede modelling; the fallacy of this argument becomes apparent when one notes that the investigator must have some model, usually subjective and not clearly articulated, in mind to guide any of his data collection.

Perhaps the most difficult task in watershed management simulation is to ensure that resource specialists, who are usually not trained in modelling, are intimately involved in model building and testing. Whatever mathematical and simulation framework that is considered appropriate must incorporate the ideas and information of such specialists, and must further provide feedback about the consequences of these ideas when incorporated into an overall prediction of system change.

The intent of this paper is to describe a workshop approach to interdisciplinary modelling, and to outline two watershed models that have been developed by resource specialists using the approach. Each of these models was conceptualized and implemented in a 5-day workshop meeting involving 15-20 scientists from Environment Canada and 5-7 model builders from the University of British Columbia. One model is concerned primarily with interactions between forestry, fisheries, and recreation activities in small coastal watersheds of the Pacific Northwest; scientists from several Environment Canada laboratories and offices in British Columbia were involved in its development. The second model tries to examine potential impacts of hydroelectric development in the LeGrande River Basin, James Bay Area, Quebec; most of the personnel involved in its development were from Environment Canada headquarters management staff in Ottawa. We choose these examples as extremes to show that the workshop approach can be applied to a wide variety of problems and personnel situations from very narrow and research-oriented to very broad and policy-oriented.

TACTICS OF WORKSHOP ORGANIZATION

Most of the time required to develop a typical simulation model is tied up in computer programming, juggling data, and achieving communication between model builder and subject matter expert. Identification of variables, relationships, and appropriate mathematical format usually proceeds very quickly. A small group of programmer-modellers, working with purely hypothetical data drawn out of the air as needed, can put together a very respectably complex model in a few days. Our modelling workshops are essentially attempts to bring together the communication and implementation phases of modelling into a single, efficient time package.

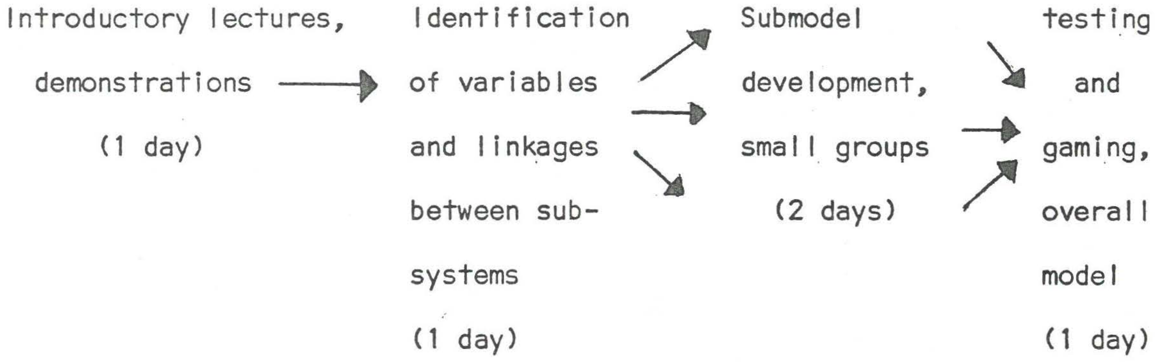
Because computer programs require the use of many arbitrary definitions and conventions that must be chosen by the programmer, it has proven unwise to have too many people involved in model implementation. We have found it most efficient to have one programmer for each major subsystem under consideration, along with a maximum of four subject matter specialists. Workshops with more than six groups of this kind become unmanageable. It is critical that each programmer have a reasonable grasp of the subject matter and jargon of the specialists with whom he will deal. Programmers with training only in mathematics or computer science are often less than useless, because they tend to introduce still another confusing jargon. Our best modellers have been resource students who have picked up a bit of programming on their own or through one or two undergraduate courses. It is essential that the programmer and the participants view the mathematical and programming work as technical translation, rather than as a fundamental addition to the conceptual understanding of the problem.

When programmers with some model building experience are used, it is not important that the participants have any special background training. The only requirement for effective participation is a willingness to be a bit simple-minded and general in looking at each part of the system. Quantitative models can only capture some simplified features of any system, and we have found that many specialists find it impossible to think about simpler rather than more complex ways to view their parts of the system. In other words, most people find it easier to take a system apart into smaller conceptual pieces; putting the pieces together into some simplified overview is much more painful, because it requires that the specialists exercise some judgment about the relative importance of each piece. About all that can be said in general is that the best workshop participants are usually those people who have had to deal with practical problems, where judicious simplification is usually necessary to get any answer at all.

During most workshops it is important to have experienced model builders who can carefully avoid the use of mathematical jargon. Participants have no way of judging the importance of unfamiliar terms, so they often believe that the modeller has said something profound when he uses a term like "matrix" instead of "table". Such a slip can have really serious consequences if it leads the participant, who usually has the best conceptual understanding of the system, to think that the modeller has some special understanding of what is happening; a lot of models are filled with elegant but irrelevant mathematics. It is critical that the participant understand exactly how his ideas are being translated for the computer. The business of translation makes the model builder's job harder, but there is little about model building that cannot be stated in everyday terms with a bit of thought.

We have used a variety of computer systems, ranging from an IBM 1130 (8k, card reader, and printer) through an IBM 370-155 with remote batch processing. The best systems we have found so far have been those with interactive terminal capability and special programmed packages for input and output (Hilborn, 1973). The interactive terminal systems allow programmers to type models directly onto disk storage, with instant access for debugging and test runs; programming time can be cut to an order of magnitude less than would be required with the usual batch processing. Also, interactive systems make it much easier to do repeated runs of a model, as gaming exercises.

We have held over a dozen model building workshops in the past three years, varying in length from two days to one year (with weekly meetings). For most purposes, the optimum seems to be one or more 4-5 day long sessions, separated by not more than two months. Irregular short meetings (few hours) spaced more than a week apart are almost sure to be unsuccessful. One compromise that we have used for particularly difficult problems has been to hold two one-week sessions, a month apart. The model is conceptualized during the first session, then data juggling and programming are done between the sessions, and the second session is devoted to testing, modification, and gaming. The workshop organization that we have found most useful is shown below, for a typical 5 day session as used with each of the watershed models:



The introductory lectures and demonstrations are fairly straight forward, and usually involve the complete development and implementation of a very simple (2-5 variable) model.

The really critical time is during the second day, when the general problem for the meeting is made explicit and divided into manageable components. It is here that the general level of abstraction of the model is decided by identifying the list of state variables to be simulated, and it is made clear exactly what information must be generated about each component of the system in order to simulate the other components. The most common problem encountered at this stage is that specialists want to build unnecessarily detailed models for their own subsystems; when serious conflicts do arise, we simply attempt to sketch out two alternative sub-models, one simple and one detailed, and try to decide how their behaviour will differ. The more detailed alternative is selected only if it appears that the behaviour of the overall system model will be affected.

It is emphasized that the output of the second workshop day must consist of a list, for each major subsystem, of the variables that must be simulated by that subsystem modelling group for use in the other submodels. It is left completely up to each subsystem group to decide what other variables to consider, knowing that their central objective is to generate these linkage variables. The second day is a particularly valuable part of the overall workshop, since here most of the communication takes place between specialists of different disciplines.

After the identification session, the workshop programmers meet and decide on computer variable names and other programming conventions. Each submodel can then be programmed and run alone with dummy values for input from other submodels, and any combination of submodels can be tacked together quickly. Dummy values can be replaced by dynamic calculations as other submodels become available.

The participants then divide into smaller groups, each led by a programmer-modeller, to develop the submodels. The emphasis in these sessions is on laying out the basic components of change of each variable assigned to the subgroup, and on graphical description of functional relationships between change and other variables being simulated. For example, the first step in developing a fish population model would be to state the basic components of population change as "new population = old population + recruitment + growth - natural mortality - harvest". Next, each component of change would be related graphically to other factors being considered. No attempt is made to develop elegant mathematical formulae for the functional relationships; finding an equation of the right shape is considered the programmer's task. Also, we defer questions of data availability and parameter estimates until after the overall conceptual framework has been laid out with graphs and flow charts; otherwise the group invariably gets sidetracked on questions (often trivial) of data acquisition. It is usually necessary to reiterate, frequently, the idea that a major goal of the exercise is to identify as many information gaps as possible, and to assign some relative importance (sensitivity) to each.

The business of programming, keypunching, and debugging each submodel is usually left entirely to the group programmer while the participants assemble relevant data. The participants work through the completed program, with the help of the programmer, to ensure that he has translated their conceptualization as intended. Problems can arise at this stage if the programmer encounters a particularly difficult coding problem and finds that he must use some additional simplifying assumptions in order to complete his task within the time available. Such coding problems are most commonly associated with the representation of spatial interactions in the system.

After the groups have the various submodels working separately and producing reasonable answers, the programmers sit down as a group and put together the overall system model. Almost invariably, errors arise through confusion about variable names, units of measurement, and extent of information exchanged between submodels. Formulation of the submodels has usually indicated that other variables need to be generated besides the ones originally agreed upon; decisions about these variables are made by informal discussion between subgroups, and usually a few of these variables are overlooked in the rush. The overall process of interfacing submodels usually takes about one full evening, if each submodel is already working properly.

The final day of testing and playing with the overall model is usually a confusing time. The typical model has many variables and several hundred parameters; also each submodel can usually accept several management interventions. The assortment of possible tests and analyses is staggering. To make things simpler, each subgroup is asked to itemize a few key runs that test sensitivity to parameters and management interventions. These basic runs are made first, and further runs decided upon by discussion among the participants.

A major problem during the testing session is to ensure that the model output is both comprehensible and comprehensive. Tables of numbers are very difficult to read, so graphical output is necessary. When many variables are graphed or displayed for each run, the process of interpreting the results can be time consuming and confusing. So, each group is asked to generate one or two key indicators for the performance of its submodel, such as a general index of population size, an index to economic well being, or the like.

The workshop closes with an evaluation session aimed at identifying key areas for future research work and obvious implications of the model for management practice. Only at this point is emphasis placed on the disparity between the kinds of data available, and those needed for the model. We have found it important that this overall evaluation not be deferred until weeks or months after the session, since participants always seem to quickly forget most of the ideas that are brought out by the modelling exercise.

THE SILT CREEK EXERCISE

The economy of western Canada is partly dependent on three major resource activities: forestry, salmon fisheries, and outdoor recreation. These activities are often centered around small coastal watersheds like the hypothetical Silt Creek shown in Figure 1. Environment Canada devotes considerable research effort to forest management practices and is responsible for coastal fisheries management; recently a large research program was initiated by the Fisheries Research Board to explore impacts of forest management on salmon production in a small watershed (Carnation Creek). However, there has been rather poor communication between the forest and fisheries agencies; the Silt Creek Workshop was intended to bring these disciplines together for a look at mutual research needs and possible management tradeoffs for small watershed systems in general. A hypothetical area was chosen to help participants focus their attention on conceptual problems rather than routine questions of data acquisition. The workshop ran for five days, with twenty participants from all of the Environment Canada offices in B.C.

A first step in the workshop was to identify major areas of disciplinary concern (submodels) and the information that would have to be transmitted between these areas in order to simulate watershed behavior over long periods (15-100 years). The result of this effort was an information table (Table 1) showing exactly what each discipline-oriented submodel was expected to produce. The discussions leading to Table 1 also made it possible to agree on the degree of spatial resolution needed to adequately represent local management activities and transport of materials; it was decided to treat the watershed as a series of 160 acre parcels (Figure 1), each homogeneous with respect to forest stand conditions, runoff characteristics, and stream condition. It was made clear

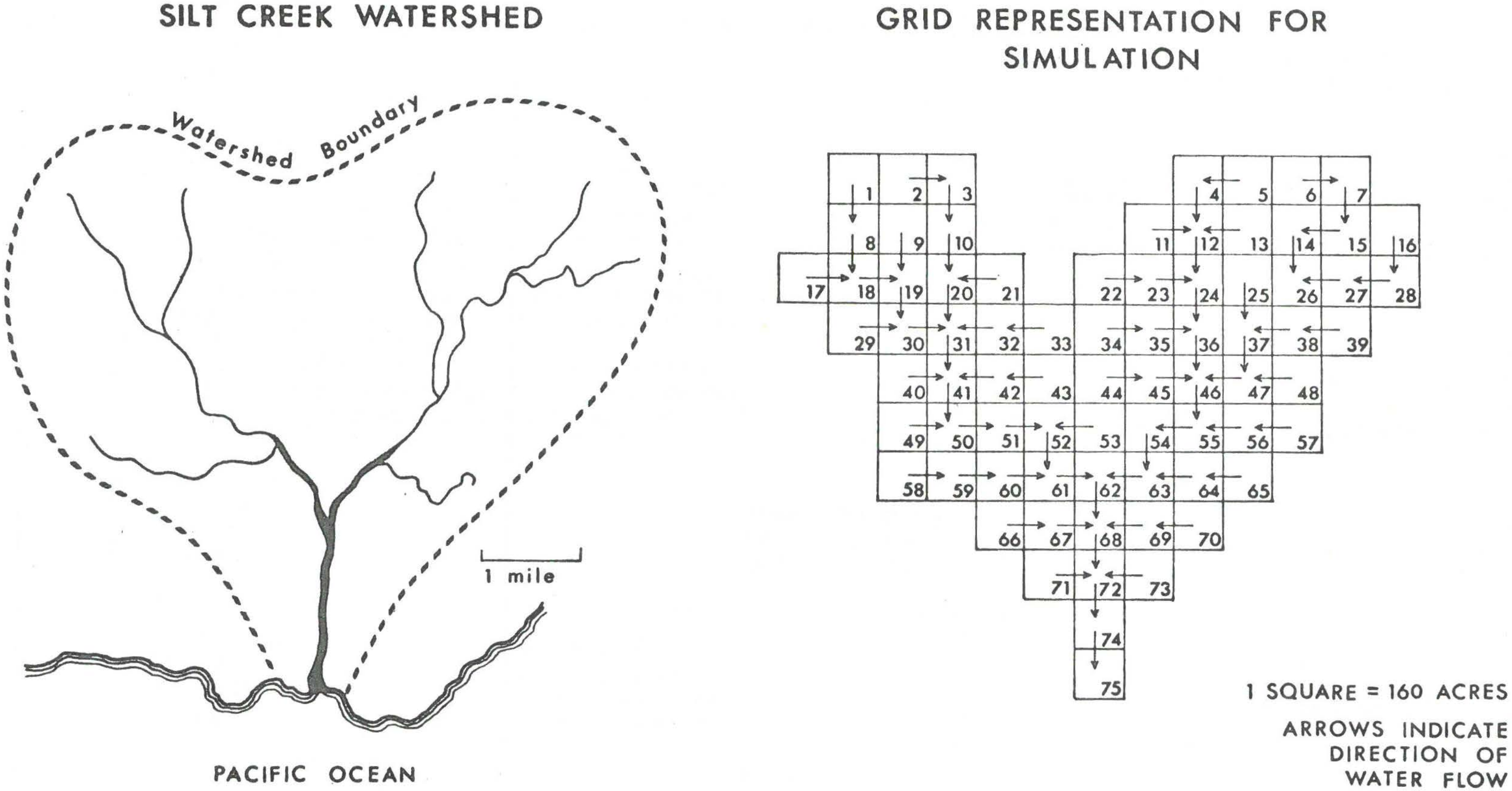


Figure 1. The Silt Creek Watershed and its abstract representation in the simulation model. Each grid area is assumed to have homogeneous forest type and stream conditions.

Table 1. Information transfers in the Silt Creek watershed model. Each row-column position shows variables simulated by the row submodel for use in the column submodel.

FROM OR SUPPLYING SUBMODEL	TO OR USING SUBMODEL					
	Water Flow and Quality	Salmon Population	Inshore Marine Environment	Forest Production and Management	Recreational Land Use	Environmental and Economic Impacts
Water Flow and Quality	Monthly water flow by area, pollutant transport	1.Summer & winter flows by area 2.Silt & nutrient concentrations 3.Stream bed silt load	1.Seasonal flow at river mouth 2.Silt,coliform, & nutrient concentration at stream mouth		1. Summer concentrations of silt, coliform, nutrients	1. Summer concentrations of silt,coliform, nutrients
Salmon population		Population dynamics in response to habitat and harvesting			1. Annual catch and catch per effort in spawning stream	1. Annual commercial catch
Inshore Marine Environment			Production of oysters in response to habitat			1. Annual oyster production, saleability
Forest Production and Management	1.Stand conditions (slash,regenerating,mature) 2.Silt & nutrient inputs per area 3.Buffer strip width	1.Location of slash blockages to fish passage 2.Stream bank vegetation (yes or no)		Spatial patterns of tree production and utilization	1.Stand conditions by area 2.Ownership 3.Road access pattern	1. Annual volume cut 2. Annual road miles constructed
Recreational Land Use	1. Nutrient,silt, and coliform inputs by area	1. Man-days of salmon fishing in stream		1. Land area held for cabin use	Demands for cabin lots and other recreation	1. Number of cabins constructed 2. Total man days of use
Environmental and Economic Impacts	Fisheries and forestry operating levels set by intervention				1. External demand for land	Summary of benefits and costs of resource use

that the submodels had to represent: (1) the dynamics of individual areas in terms of a single general set of calculations that could be repeated every simulated year for every area, with different starting values; and (2) connections between areas in terms of forest seed dispersal, water movement, and the like.

The submodels for each disciplinary area were then developed and tested by small groups of participants. These submodels are listed as the row and column headings in Table 1; the following paragraphs give an overview of the factors and relationship considered in each. The intent of this overview is to show the kinds of factors that can be considered in a short workshop exercise; the description should not be considered a definitive outline for watershed models in general.

Forest Management

The forestry submodel is divided into two major sets of calculations, for production and for utilization. The production section is essentially a stand development model; for each 160 acre area in the watershed, it calculates changes in wood volume present as a function of tree age (since last logging), management practice, and forest site quality (areas near the mouth of the watershed were assessed to have the highest site). For any simulation run, management practice is defined as a series of yes or no decisions concerning planting, stand thinning and fertilization. A different volume production function is used depending on which decisions are taken. The stand age and volume estimates are used to generate indices of overall forest condition for each area (e.g. slash, regenerating, mature), which are used in the hydrology, fisheries, and recreation demand submodels.

The forest utilization calculations are essentially a bookkeeping system to keep track of the location, timing and pollution impact of logging operations. Any logging pattern across the watershed over time can be established by intervention before a simulation run. When an area is logged, its stand age and volume are set to 0. Depending on another intervention, silt, nutrients and stream slash blockages may be created for use in other submodels. The silt input and blockages to fish passage are assumed to persist for several years after logging. A road building pattern, represented in the computer by a time-varying access code for each 160 acre area, is also established by intervention. Road construction and presence are assumed to result in silty loads in adjacent streams, independent of actual logging operations.

Some forestry problems were not considered at all, for example, fire and insect damage or intensive tree farming activities. Thus the forestry submodel produces an optimistic picture of natural productivity. Treated as a black box, it has as its main inputs patterns in space and time of forest management, and as output it produces patterns of forest yield and pollution.

Hydrologic Conditions and Water Quality

Water flow patterns and water quality (silt, nutrients, coliform count) are simulated on a monthly basis in order to provide seasonal extreme conditions for the fishery submodel. Each 160 acre area is assumed to have a monthly contribution to runoff dependent on its forest stand condition. Higher winter and lower summer runoffs are associated with recently logged areas. No attempt is made to relate runoff explicitly to precipitation, ground water movement, and evapotranspiration; runoff estimates used in the simulation are assumed to be the result of these processes. Monthly runoffs are accumulated downstream from area to area to give an overall picture of stream flow for each month in each area. The computational bookkeeping for downstream calculations is simplified by assuming that each area has one and only one area to which it delivers water.

Silt, coliform and nutrient inputs to each area are estimated in the forestry and recreation submodels. The hydrology submodel dilutes these inputs, based on water flow, and moves them downstream. Nutrients and coliform count are assumed to be conserved (not used up or degraded) as they move down the watershed, but silt concentrations may change due to sedimentation and resuspension. The basic dynamics assumed for silt transport are shown in Figure 2. The key feature of these calculations is consideration of accumulation and later release of silt by the stream gravel bed; release from the bed may result in silty conditions for several years after any pollution source has been stopped.

Salmon Population Dynamics and Harvest

Though several salmonid species would normally occupy an area like Silt Creek, we chose to simulate only coho salmon (*Oncorhynchus kisutch*) as a typical example or indicator population. One problem that appeared immediately during the development of this submodel is that salmon may home to very specific areas within the watershed for spawning; thus we chose to treat the fish in each stream section defined by a 160 acre area as a separate population (with potential for straying and dispersal to other sections).

The life cycle of fish is treated as a series of stanzas: egg, fry, smolt, first ocean year, second ocean year, spawning. Thus the state of the population in the model is characterized by a large table of population numbers, where the rows represent stream sections (defined by 160 acre areas) and the columns represent stanzas. Survival rate in fresh water stanzas is assumed to be a function of stream flow, silt and nutrient loads, population

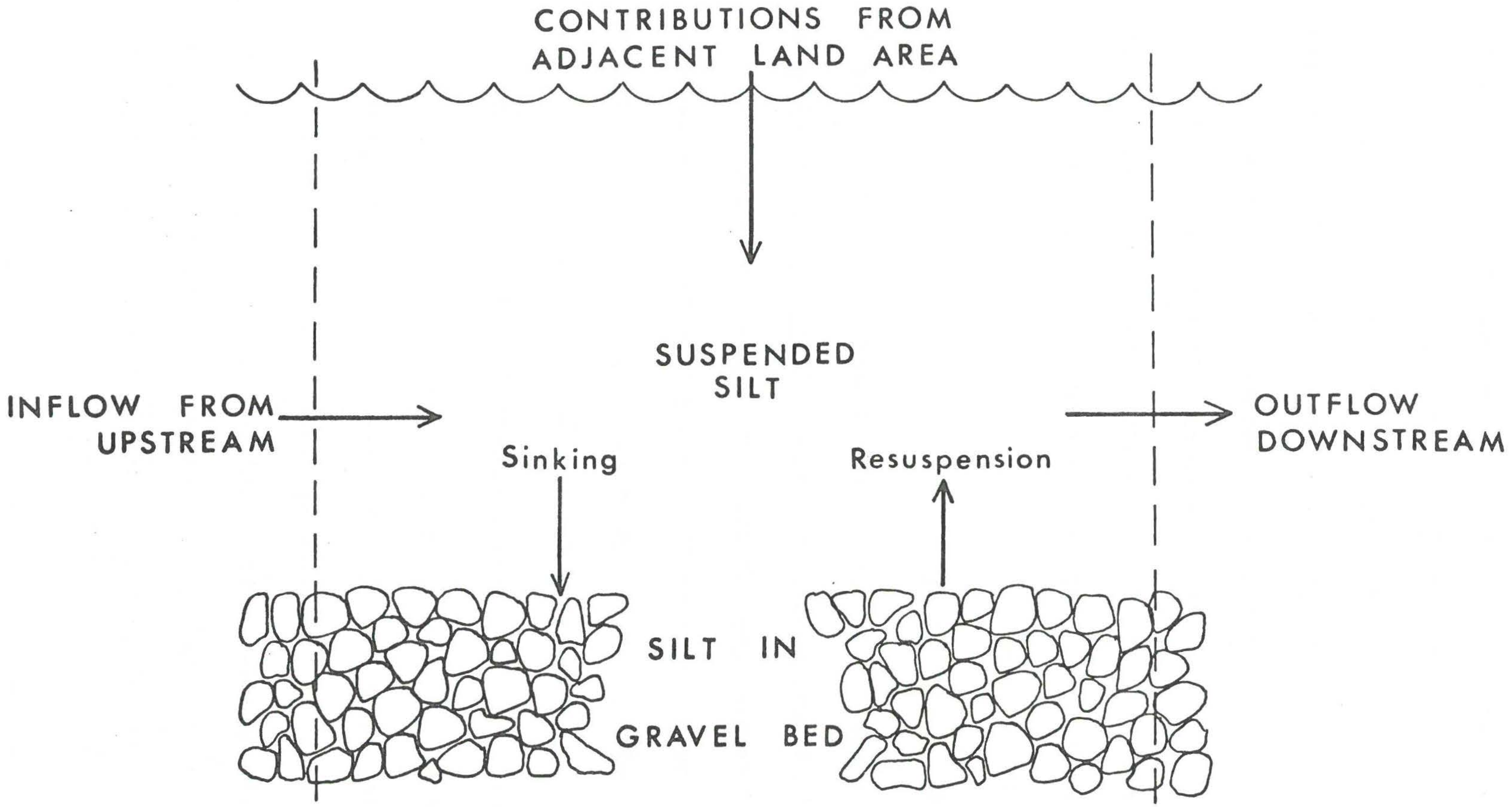


Figure 2. Example of dynamic interactions considered in the Silt Creek Model. Silt transport assumptions are critical in assessing interactions between forestry and fisheries management practices.

density, and stream bank cover conditions (estimated from forest conditions). Dispersal is assumed to occur in the fry and smolt stages, so that juvenile fish are spread evenly over all accessible portions of the stream network. Most adults are assumed to home to the section where they spend the fry stage, but a small fraction are distributed across all available sections to simulate straying. Logging operations may result in blocks to fish passage; adults unable to reach their home sections are distributed over all accessible sections in proportion to relative water flow in these sections.

Beyond a basic mortality rate, survival in the ocean and spawning stanzas is assumed to be affected only by fishing. Ocean harvest rates (commercial plus recreational) are chosen by intervention before each simulation run. Recreational fishing effort for spawners moving upstream is estimated each year in the recreation submodel; catch is related to this effort with a standard fisheries catch curve (exponential function).

Inshore Marine Productivity

It was assumed that Silt Creek empties directly into a protected area of the Pacific Ocean, such as the Strait of Georgia. Pollutant materials (silt, coliform bacteria) from the stream could affect productivity of the adjacent marine environment, particularly for benthic organisms. As in the fishery submodel, we chose to look at only one indicator species, the Japanese oyster. The marine productivity submodel attempts to predict silt and coliform concentrations along the shoreline adjacent to the stream mouth, and to relate these concentrations to potential commercial production of oysters.

No attempt was made to develop a comprehensive hydrodynamic model to predict transport patterns of materials in the ocean. Instead, it was simply assumed that water movement is nearly random, so that average concentrations decrease as the inverse square of distance from the stream mouth. Parameters for rates of decrease were chosen so as to represent typical rates of silt settling and coliform death as observed in empirical studies in waters along the B.C. coast. Silt is assumed to affect oysters by decreasing spat settling success and growth rate. Overall potential production rates for representative areas along the shoreline are calculated from spat success and growth rate, under the optimistic assumption that spat will be abundant every year unless silt is limiting. Coliform counts are assumed to affect only the marketability of the oysters; maximum permissible coliform levels are set by intervention before each simulation run.

Recreational Land Use

The fisheries, forestry, and water submodels generate an overall picture of resource conditions across the watershed. The recreation submodel attempts to predict how these resources will be used as a function of environmental quality and land ownership policy. For any simulation run, part or all of the watershed may be placed in public ownership (parkland) before or after logging. Each 160 acre area of this public land is assumed to receive recreational use (man days of hiking, hunting, and fishing) in proportion to its accessibility and perceived environmental quality. Accessibility is assumed to be inversely proportional to distance from the nearest logging road. Perceived environmental quality is measured as a 0-1 index; virgin forest areas with clear water and many fish are given index values of 1 while areas deficient in any of these characteristics are given smaller index values.

Subdivision into recreational lots and potential cabin development is assumed to occur on all non-park land in the watershed, except that designated for forest management. Marine waterfront lands near the stream mouth are assumed to be fully developed when the simulation begins. The rate and spatial pattern of inland lot development are assumed to depend on environmental quality (as represented by the combined forest-water-fish index), on road access, and on the degree of crowding as development proceeds. In each simulated year, the model first estimates a potential demand for lots (total number of lots that could be sold); this potential demand can be varied over time by setting a growth rate parameter before any simulation run. A gravity model is used to allocate demand over available lots, where the gravity weighting for each lot is a function of access, quality, and number of lots already developed in the same 160 acre area. The lots with highest gravity weighting are developed first.

Cabin construction is assumed to result in silt input to adjacent stream sections, and recreational use-days are assumed to result in some input of nutrients and coliform count to streams. Cabin use is assumed to be more polluting than camping or day use. The pollutant loadings due to recreation for each 160 acre area are added to loadings due to forestry operations to give an overall input picture that is used by the hydrology-water quality submodel.

Since we expect potential demand to be largely a function of conditions (population, alternative recreation areas) outside the watershed, unconditional predictions from the recreation submodel are not likely to be meaningful. Its predictions are useful only to the extent that they indicate some broad response patterns and general impact problems that might arise for some different demand patterns that could occur.

Environmental Quality and Economic Impacts

A final submodel in the Silt Creek exercise was devoted to the representation of regional economic impacts of watershed development, and to generation of overall indicators of environmental quality. This submodel is essentially a bookkeeping system with no dynamic relationships or feedbacks to other submodels. It takes information on rates of return from logging, fishing, oyster farming, and recreational development and compares these rates to operating and capital costs for each industry; the result is a measure of net economic return. The total number of jobs in primary resource industries is also generated.

The environmental quality indicator mentioned above (recreation submodel) is estimated for each 160 acre area in this submodel. There is also an indicator for overall quality of land (area of mature forest divided by total area) and for water quality (total salmon run divided by the run size expected under pristine conditions). These indicators we designed to give a general feel for how the Silt Creek area would look over time, under alternative management strategies; they are not meant to be absolute measures of quality.

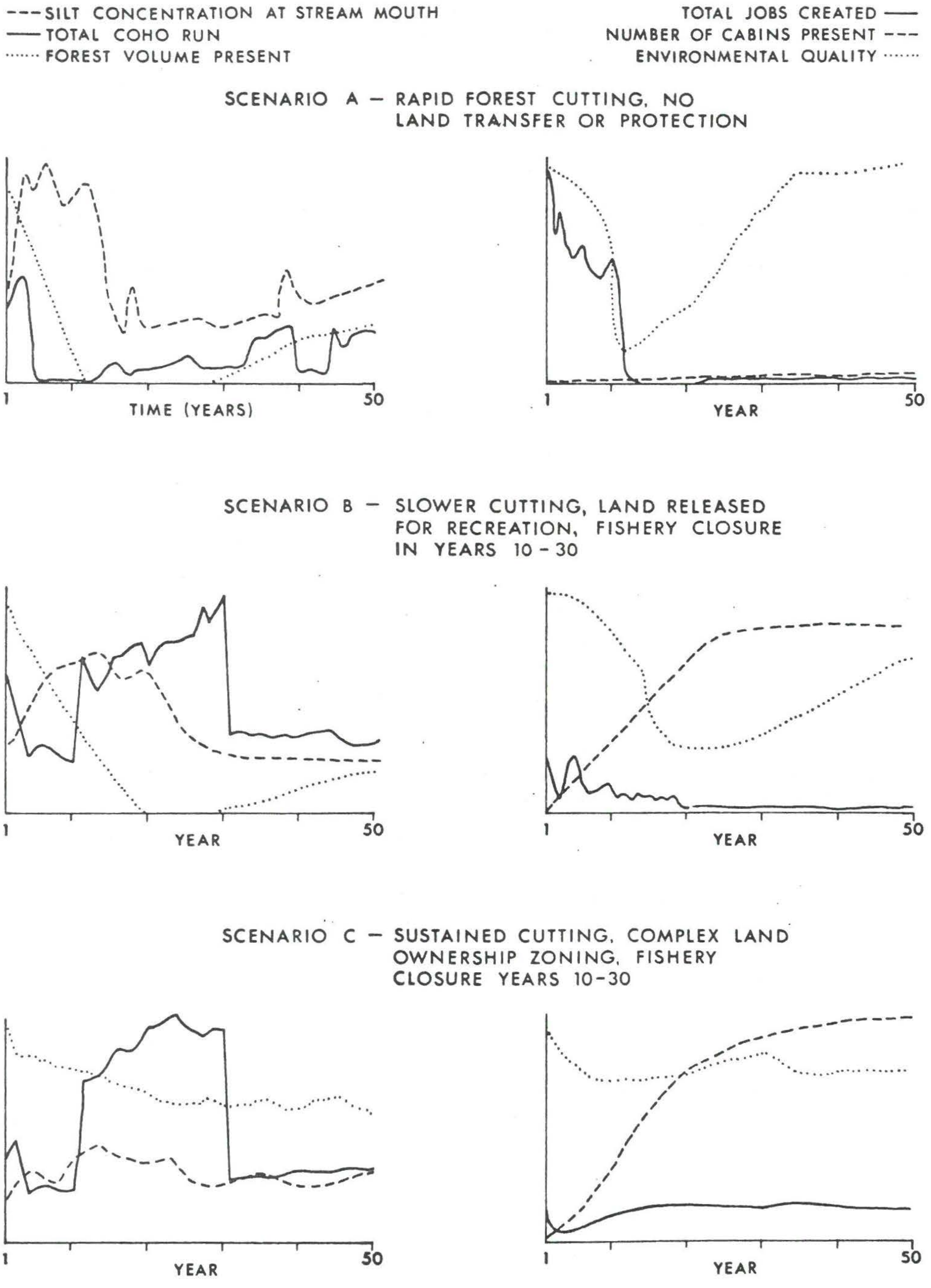
Results of the Silt Creek Exercise

It must be remembered that the Silt Creek model described above was developed over a very short period of time (3 days), so many factors were necessarily omitted or overlooked. Nevertheless, the model gives a rather more comprehensive picture of watershed problems than we expect is used as the basis for most management decisions today. Most participants in the workshop indicated that it gave them a valuable chance to look at the problems and assumptions of other disciplines, and several indicated that it had helped identify research areas where critical information is lacking.

Some sample results from the overall model are shown in Figure 3, to indicate how it might be used to compare alternative management strategies. Most participants felt that test runs such as these that were made during the workshop were not particularly valuable, since there was little time to develop parameter estimates. Interactions between the submodels resulted in few really surprising predictions of overall system behavior, but Figure 3 shows some results that had not been anticipated by the participants.

In runs A and B in Figure 3, for example, the model predicted that there should be no simple relationship between stream deterioration due to logging and changes in salmon runs; instead of a gradual population decline with worsening conditions, the population shows almost no response until some "resilience limit" is reached. Beyond this limit, the population declines catastrophically without producing any clear warning signs that would be detected with appropriate biological monitoring. Other test runs with the model suggest that this general response pattern will occur for about all reasonable parameter estimates. The basic reason for the pattern is that salmon runs normally contain a large excess of spawners relative to space available in the stream for egg deposition and rearing of young; this excess is usually not reflected in future population sizes, except when conditions for the average spawning fish become very poor.

A second interesting prediction of the model can be seen by comparing the environmental quality index plots in runs B and C in Figure 3. Though the usual cut-and-go logging tactics result in a severe short term decline in environmental quality, the long run picture is not so bad. On the other hand, integrated multiple use with only the sustainable logging cut taken each year



SCENARIO A – RAPID FOREST CUTTING, NO LAND TRANSFER OR PROTECTION

SCENARIO B – SLOWER CUTTING, LAND RELEASED FOR RECREATION, FISHERY CLOSURE IN YEARS 10 - 30

SCENARIO C – SUSTAINED CUTTING, COMPLEX LAND OWNERSHIP ZONING, FISHERY CLOSURE YEARS 10-30

Figure 3. Typical simulation results from the Silt Creek Model, showing how it can be used to compare alternative management strategies. Only relative values over time for selected variables are shown, to emphasize that absolute quantitative predictions from such models are likely to be very misleading.

(supposedly the ideal for B.C.) results in lowered environmental quality all the time; clear cut areas and some stream pollution are always present. Though there may be other ecological interactions not considered in the model that make rapid cutting a poor policy, the suggestion is clear that we need to take a hard look at the apparent benefits of multiple use management.

It is instructive to itemize a few of the data gaps that were identified while constructing the model, to demonstrate that models do not require peculiar kinds of data that are really not needed to make management decisions. First, it was obvious that there is very little data on the quantities of silt and nutrient that can be expected to run off a logged area, given different logging practices; we had to estimate these loadings from crude data on changes in soil depth collected in erosion studies. Second, there is little empirical understanding of silt transport into and from gravel beds, especially in relation to freshet runoff conditions. Finally, we were surprised to see that noone knows how flexible salmon are in choosing new spawning areas when homing is impossible due to slash blockage or when silt conditions would prevent successful egg hatching. It is not even possible with existing data to answer crude questions like: suppose half of the watershed is blocked off; will fish homing to this area spawn in the other half of the system? It was depressing to see that questions like this had not been identified as important, and some answers obtained, a long time ago.

JAMES BAY MODEL

In contrast to the Silt Creek exercise, the James Bay Workshop was geared to a real and pressing resource problem, the LeGrande River Basin emptying into James Bay, that will involve millions of dollars in impact studies by various resource agencies and the livelihoods of several thousand people. The LeGrande area is scheduled for a large hydroelectric development (Figure 4) over the next decade. The area supports an Indian population of 1500, and has great potential as a recreation area especially for people from Montreal. Our workshop was an attempt to involve high level policy makers as well as field researchers (20 participants in all) in an integrated look at development impact and also long range management of the area. An immediate goal was to see if Environment Canada should modify its existing plans for impact studies. Again, we did not expect to produce any solid predictions in the 5-day meeting.

We began the James Bay exercise by identifying a basic set of specific predictions that we would expect the model to handle; this was a tactic for helping to identify problems and questions of interest to Environment Canada. First, it was decided that the model must represent the time course of broad impact on land area, water coverage, and shoreline of the hydro-electric dams and diversions. This is essentially a data summary and bookkeeping problem. Second, we hoped to show the overall biotic response over time to these gross changes; it was expected that the development will destroy habitat for some organisms, but improve conditions for others. Third, it was expected that hydroelectric development will alter the temporal stability of aquatic and shoreline environments, by reducing variation in water flows. The model was expected to represent effects of this stabilization on vegetation, fish and wildlife. Fourth, construction and maintenance activities are likely to generate various water pollutants, especially silt. The model was expected to represent the spatial and temporal distribution and dispersal of these materials, and give some prediction of biotic impacts for at least extreme conditions. Finally, development will dramatically alter

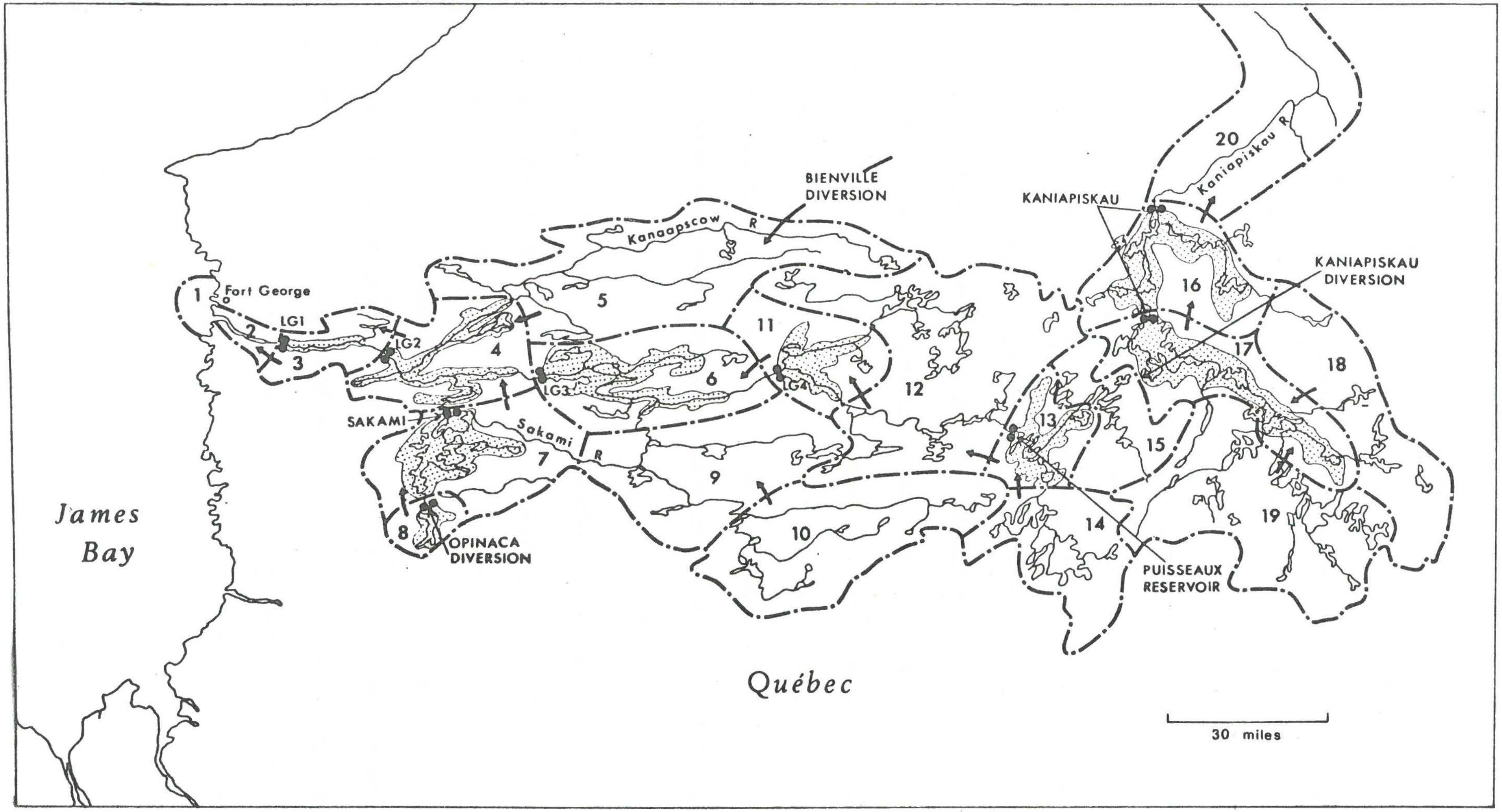


Figure 4. The LeGrande River Basin of the James Bay Area, showing subareas considered homogeneous in the simulation model (dotted lines), major development sites (light arrows and double dots), patterns of water flow (heavy arrows), and areas to be flooded (stippled).

accessibility of the area, which may result in greatly increased human activity. The model was to represent the general impact of increased exploitation on animal populations of the area.

The identification of these problem areas led to the subsystem breakdown and information transfer scheme shown in Table 2. System components missing from this table include the marine environment and the atmosphere. Hydroelectric development is expected to alter marine conditions, especially winter ice patterns, and there is also the possibility of climatic changes. Meaningful predictions concerning these questions would require the development of very specialized and complex spatial models, which we decided were beyond the scope of a workshop session. Along with the information table, it was necessary to decide on a system for representing spatial patterns; as shown in Figure 4, we decided to divide the LeGrande area into a series of irregular land units, with each unit containing no more than one component of the hydroelectric development (e.g. one dam) and small enough to be considered homogeneous with respect to transportation access and general productivity for wildlife and fish.

We next developed the submodels described in the following sections. Unless otherwise indicated, the calculations were set up to be done separately for each land unit in each simulated year. To save time during the submodelling sessions, we had developed before the workshop a basic data bank of land inventory and ecological information. Also, participants were advised beforehand of particular data problems that we knew would arise, so they were able to provide reasonable parameter estimates in many cases as the submodels were being developed.

Table 2. Information transfers in the James Bay (LeGrande Basin) model. Row-column conventions as in Table 1.

USING SUBMODEL

SUPPLYING SUBMODEL

	Hydrology and Hydroelectric development	Vegetation and Shoreline Environment	Wildlife Populations	Water Quality and Fisheries	Demand for Wildlife and Fisheries
Hydrology and Hydroelectric development	Water flow regulation, land area changes, construction patterns	1. Area inundated, shoreline mile changes 2. Reservoir depths, area covered & uncovered each year 3. Seasonal water flows	1. Location of active construction sites 2. Seasonal water flows and lake levels	1. Silt, nutrient, and coliform inputs due to construction operations 2. Seasonal water flows, lake levels	1. Construction and operating schedule 2. Road access pattern 3. Jobs available to indians
Vegetation and shoreline environments	1. Silt inputs along stream & reservoir banks 2. Nutrient input to reservoirs after flooding	Successional dynamics of vegetation, shorelines	1. Acreages in different vegetation types 2. Mudflat area and stream bank successional states	1. Stream bank vegetation condition (present or absent)	1. Width of mudflats along reservoirs. 2. General index of vegetation quality
Wildlife Populations			Population dynamics in response to habitat and hunting		1. Kills and kills per effort for each species in each land area
Water Quality and Fisheries			1. Silt concentrations in rivers	Pollutant concentrations and population dynamics	1. Catches and catches per effort by species and area
Demand for Wildlife and Fisheries		1. Land used for campsites	2. Hunting effort for each species in each area, indian and recreational	1. Coliform and nutrient inputs due to campers 2. Fishing effort by species and area	Demand by indians and whites as a function of quality and past returns

Hydrology and Hydroelectric Development

The key submodel developed during the workshop was that concerned with hydrologic conditions in relation to hydroelectric development. It takes as input (before any simulation run) an arbitrary time plan for hydroelectric construction across the land units. This plan is combined with a year to year simulation of water runoff patterns to give an overall picture of water storage, seasonal flow rates, and power generation.

Each simulated year begins with an evaluation of seasonal runoff contributions from each land unit. In the absence of dams or divisions, these runoff contributions are simply cumulated downstream to give flow at the major river exit from each land unit. For units receiving development, the model considers three activity phases: construction, filling, and sustained regulation. During the construction phase, the submodel generates only pollutants (silt) below the construction site. During the filling phase, the model generates pollution inputs, and reduces flows through the unit to a minimum set by intervention before the simulation run.

For each reservoir site, the model has as input an empirical depth-volume-area covered relationship which is used to regulate filling and to simulate sustained regulation. The regulation calculations consist simply of an attempt to keep outflow at the dam constant, given expected water inflow and constraints on permissible fluctuation of water level (also set by intervention). The flow control patterns are calculated on the assumption that every year will have average flows, in other words that the hydroelectric planners will have no means to forecast runoff conditions. Thus reservoirs are depleted in simulated dry years, and water is wasted in wet years (provided reservoirs are full). Minimum and maximum pool constraints, set by intervention, are used to see that no reservoir is dried completely and that water is added to storage whenever possible.

Power output is estimated as an empirical function of outflow for each reservoir, and this along with silt loadings, road access indices and land area plus shoreline changes constitute the output to other submodels each simulated year. The construction plan is used in the Land Use Demand Submodel (see below) to provide estimates of recreational impact due to construction workers.

Vegetation and Shoreline Environments

Plant communities in each land unit are represented by a list of acreages of various vegetation types (mudflat, marsh, willow, deciduous forest, coniferous forest). Acreages are moved from one type to another (and lost underwater) depending on water flow and reservoir stage patterns generated in the hydrology submodel. Of particular concern is the shoreline area maintained in mudflat by water fluctuation, and the successional changes in this area that may be permitted by flow control. The vegetation submodel handles this succession around reservoirs very simply by moving acreages into and from the mudflat class according to area change information provided by the hydrology submodel. Mudflat area changes along river banks are estimated from empirical flow-stage-area curves for points near the mouth of each land unit. Vegetation conditions away from the reservoirs and streambanks are assumed to be stable (at climax). The LeGrande area is too far north for commercial logging, and forest fires are not a serious problem.

As output to other submodels, the vegetation calculations provide the acreage classes and also some silt pollution estimates. River bank erosion results in some siltation, but a major source is assumed to be bank erosion along newly created reservoirs. Crude estimates of silt contribution from this source were obtained from soil depth data. The amount of shoreline soil available for erosion is stored as a dynamic variable which decreases as the simulation proceeds.

Wildlife Populations

The major animals that may be affected by the development include moose, caribou, beavers, rabbits, puddle and diving ducks, and geese. The model attempts to represent dynamic changes in these major indicator populations for each land unit, as a function of habitat conditions and harvesting demand. It is assumed that there is a carrying capacity or maximum breeding density per unit area for each population on each vegetation type, or when appropriate per mile of shoreline or stream. For example, geese use primarily the mudflat areas, for fall staging, so mudflat acreage is used to estimate capacity for this population. Caribou require woodland areas and marshes for winter range, and estimates were available of their maximum population densities in these habitats.

Annual net population change in the absence of harvest is assumed to be a function of spring population size and degree to which the carrying capacity is filled. Population increase per breeding animal is assumed to decrease toward zero as the population nears carrying capacity (logistic growth model). Migration between land units is assumed to be insignificant for the furbearers, but large mammals and waterfowl are assumed to distribute themselves over the area in relation to habitat quality.

Mortality to hunting is estimated from hunting effort (provided by the Demand Submodel described below) and population density. Higher densities result in higher kills per hunter, while increased hunting effort results in lowered success per man. Mathematically, these relationships are represented with an exponential function similar to the catch curve commonly used in fisheries management. Different success parameters are used for indian subsistence hunting and trapping as opposed to recreational hunting by resident and visiting white people.

Water Quality and Fisheries

The water quality parameters considered in the LeGrande area were the same as for the Silt Creek exercise: silt, nutrients, and coliform count. Essentially the same bookkeeping procedures are used to move these materials downstream from any effluent sources (e.g. construction sites). The calculations for each year begin with a picture, provided by other submodels, of input loadings across the watershed. These inputs are diluted according to water flows and expected degradation or settling rates. A special problem in the siltation calculations is the effect of reservoirs and other standing water bodies; the simple assumption is made that the proportion of silt settling out in a water body increases as a negatively accelerated exponential process toward 100% as retention time (volume divided by flow) increases. Thus a reservoir such as LG1 (see Figure 4) may prevent pollutants due to upstream construction from reaching the lower portions of the watershed.

Four indicator fish populations are considered, for the waters of each land unit: char, lake trout, northern pike, and anadromous whitefish. The first three are of potential recreational value, while the whitefish is used extensively by indians. The structure of each population is represented in the computer as the number of animals in each immature age group, plus the number of mature individuals. Each population is assumed to have specific habitat requirements for spawning (e.g. streams versus lake shores) and growth. Population changes are related to conditions in these habitats, to population size, and to harvesting effort. For example, pike reproductive rate is related to the shoreline length and water level stability of ponds and lakes; water level fluctuation during spring and summer may result in lowered production. Whitefish spawning success is related to water flow and silt concentrations only in the lower reaches of the LeGrande River, and so on.

Harvesting effort is generated in the Demand Submodel and is assumed to be concentrated on adult (mature) fish. This is an optimistic assumption; harvest of juvenile fish may have serious consequences, especially since the number of years required to reach sexual maturity is high in cold northern waters (e.g. 8-10 years for lake trout). Fishing success is related to the density of fish and to the number of competing fishermen, as in the wildlife submodel. Though the demand submodel provides a different estimate of overall fishing effort for each land unit, all waters within any unit are assumed to receive equal fishing effort; this again is an optimistic assumption, since overfishing problems may be much more severe in localized areas along roadways.

Demand for Wildlife and Fisheries

Though non-consumptive tourist use of the LeGrande area may become important, we decided to concentrate on consumptive users as the major source of resource management problems. The Demand Submodel tries to predict the amount and spatial distribution of hunting and fishing effort directed at each animal population as a function of accessibility, abundance as measured by past success, and type of restrictive regulation.

The demand calculations in each simulated year begin with an estimation of expected total demand over all land units, by the indian population and by tourists and construction workers. Indian demand is assumed to be influenced by local population size, which grows at a rate set by intervention, and by the existence of alternative sources of income such as construction jobs. The number of indians who will give up hunting, trapping, and fishing in favor of construction jobs is assumed to be a function of the abundance of game; the number of jobs offered to indians is set as a policy intervention. This is a particularly weak area of the model; if many indians choose to give up hunting and fishing, some animal stocks that are now heavily harvested (e.g. caribou) may actually benefit indirectly from the construction activities. External demand is assumed to be a function of average hunting and fishing success over the whole area, according to the graphical relationship shown in Figure 5. Demand by construction workers is assumed to be affected in the same way, though it is expected that these workers will have little time for recreation.

Next the submodel distributes overall demand across the land units. Those areas with no road access due to hydroelectric construction receive very low effort relative to accessible areas. Units that have had high hunting or fishing success the previous year receive proportionately more effort. Full knowledge on the part of hunters and fishermen is assumed as to where the best places will be to go; thus it is implicitly assumed that people will explore around the area to find high quality conditions. A series of interventions before any simulation run allow for regulation of demand through closure of units or restriction of total use to campground areas with limited capacities.

From the external demand, construction work, and indian population estimates, the demand submodel generates nutrient and coliform count inputs to the major river section of each land unit. Initial test runs with the water quality submodel indicated that these inputs may be sufficient to cause problems at Ft. George, where the major indian community takes its water supply directly from the LeGrande River.

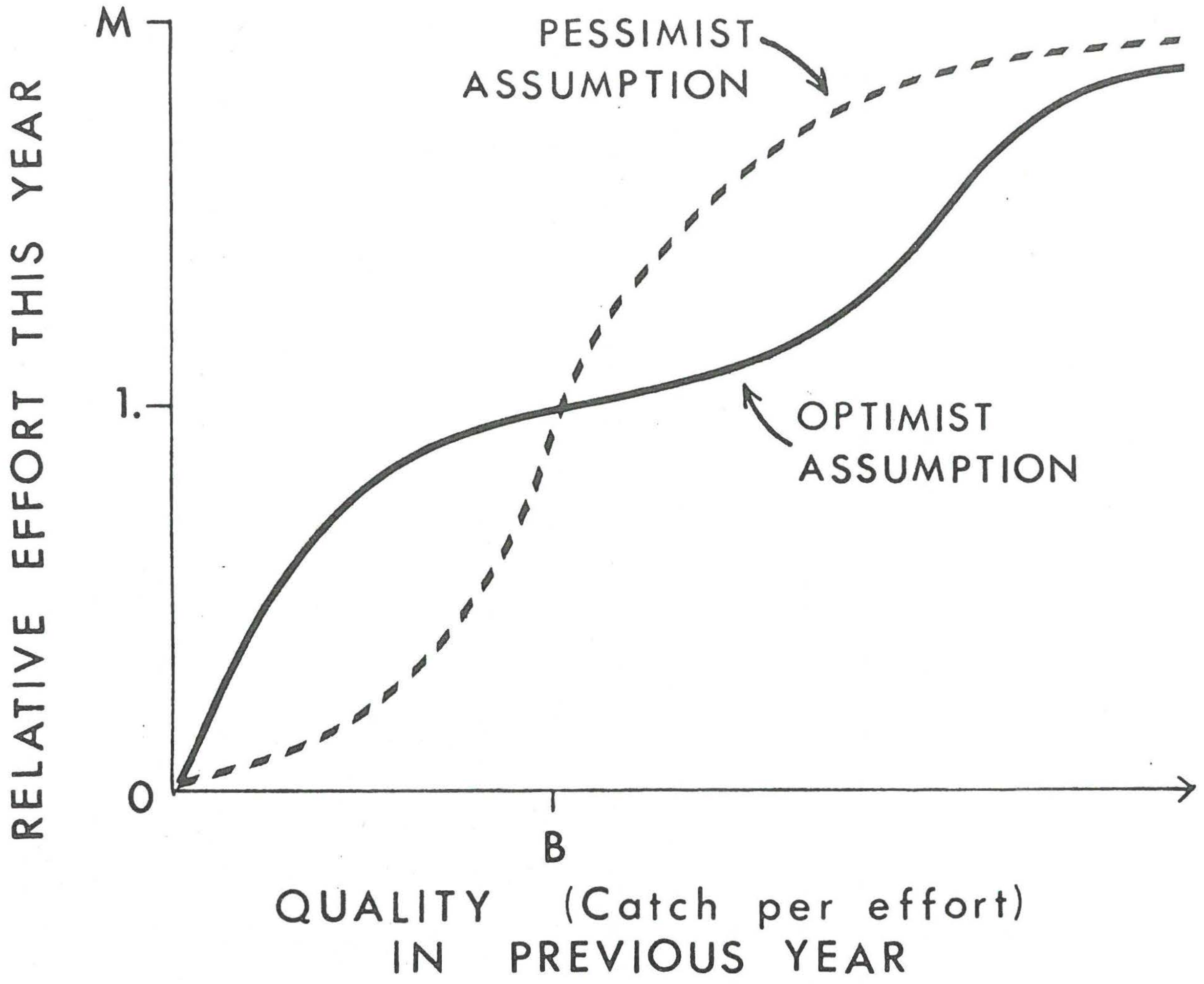


Figure 5. Example of a troublesome functional relationship in the James Bay Model. Little is known about how recreational demand will respond to changes in quality; the two alternative assumptions shown were tried in different simulation runs. The optimist assumption results in destabilization of population sizes and demand over time.

Results with the James Bay Model

As the submodels described above were being completed, it became obvious that the overall model would be able to accommodate a bewildering variety of policy options, and that sensitivity analyses on every component of possible research interest would not be feasible. So, we decided to recast the workshop participants into policy analysis groups, each representing a major interest group in the James Bay controversy. Each group was then asked to do three things: (1) develop a short list of simulation variables that best indicate those aspects of system condition that are of concern to the interest group; (2) formulate one or two overall management scenarios, each expressed as a combination of input interventions, that the group felt intuitively would represent best management; and (3) develop a set of *a priori* intuitive predictions about the effect of each intervention on each output indicator variable. After some discussion, we decided to have three of these groups: resource development, environment, and indian welfare.

Results from the scenario runs proposed by these groups are shown in Figure 6. In all three cases it was assumed that the overall hydroelectric development would occur, but with different sorts of restrictions on construction activities, management of flows and levels after construction, and access to the area for recreation. A qualitative comparison of predictions made by the model as opposed to intuitive predictions made by the policy groups is presented in Table 3. It is interesting to note that the basic impacts (positive or negative) predicted by the model were exactly opposite from what had been expected for over 70% of the intervention-indicator combinations. In every case, a simple explanation for the difference was clear after brief examination of the model structure, and the participants generally agreed that there had been obvious flaws in their intuitive reasoning.

Table 3. Qualitative summary of management interventions, and their simulated impacts according to the James Bay model as opposed to intuitive predictions of workshop participants. Sign before each slash is intuitive expectation of impact (+ for beneficial); sign after slash is simulated direction.

AREA OF IMPACT

	RESOURCES				ENVIRONMENT								INDIANS			
POLICY INTERVENTION RELATIVE TO PUBLISHED PLANS	Power generated	Indian harvests	Non-consumer recreation	Employment	Quality	Char	Trout	Pike	Whitefish	Caribou	Beaver	Geese	Harvest jobs	Welfare load	Salary jobs	Abundance of game
<u>Power</u>																
Slower dam construction	-/-	+/-	+/+	+/0	+/-	+/-	+/-	+/-	+/-	0/0	+/-	-/+	+/-	-/0	+/+	+/-
No water diversion	-/-	+/-	+/-	0/-	-/+	+/-	0/0	+/-	+/+	0/0	+/-	+/-	+/-	-/+	-/-	+/-
Control minimum water flows	-/-	+/0	+/+	0/0	+/+	+/+	+/0	+/0	+/+	0/0	+/0	+/-	+/0	-/0	-/0	+/0
<u>Quality</u>																
Clear trees in reservoir pool	0/0	+/0	+/+	+/+	+/+	+/0	+/-	+/-	0/0	0/0	0/0	+/0	0/-	0/0	0/+	+/0
Control silt input	0/0	+/+	+/+	+/0	+/+	+/+	+/0	+/0	+/+	0/0	+/0	+/0	+/+	-/-	+/-	+/0
<u>Demand</u>																
Indian job interest	0/0	+/-	0/0	+/+	0/0	0/+	0/+	0/+	0/+	0/+	0/+	0/+	-/-	-/-	+/+	0/+
Jobs allocated to Indians	0/0	-/-	0/+	0/0	0/+	0/+	0/+	0/+	+/+	0/+	+/+	+/+	-/-	-/-	+/+	+/+
Access controlled to reduce recreation	0/0	+/+	-/-	-/-	+/+	+/+	+/+	+/+	+/+	+/-	+/0	+/+	+/0	-/+	+/-	+/+

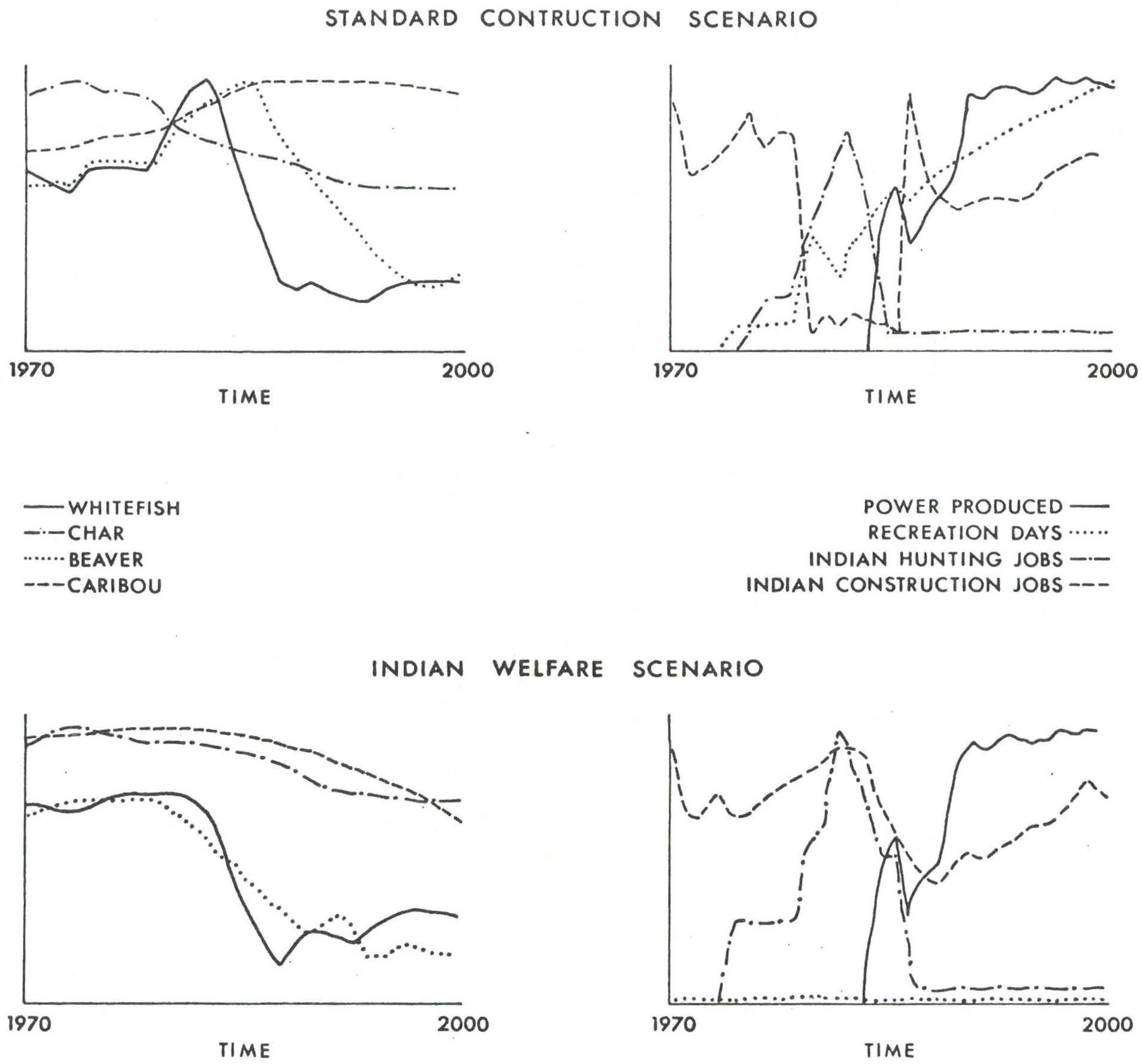


Figure 6. Sample predictions from the James Bay Model for three alternative management scenarios. All predicted values are on relative scale as in Figure 3.

The model made three major predictions that were counter to any expectations expressed either by the workshop group or in published impact statements related to the James Bay Area. First, by providing an overall bookkeeping assessment of the land and water areas involved in hydroelectric development, the model pointed out that the direct impacts of dam construction are not likely to be all that significant; only a small percentage of the land will actually be inundated. Second, by far the largest impact on fish and wildlife resources is likely to come from the increase in recreational demand; in retrospect it is obvious that even small recreational fisheries can seriously deplete northern lakes and streams that can support only a few fish per acre, turning over only once every several years. Finally, it is not simply the case that more intensive hydroelectric development in the area would result in worse environmental problems. We tested the model with the standard LeGrande Complex construction plan, then compared this to an even more elaborate dam and diversion plan that has been contemplated (The Complex du Nord). The hydrology submodel predicts that the LeGrande Complex would not result in much regulation of water flows and levels, so reservoirs would be surrounded much of the time by large mudflat areas that would not be attractive for recreation (geese might prosper by these areas). On the other hand, the complex diversion scheme in the Complex Du Nord should result in much stabilized flows and levels, making river banks and reservoirs more attractive for recreation (but some waterfowl habitat would be lost).

Considering these predictions, it is not surprising that the workshop suggested several possible changes in impact assessment studies. In particular, it appears that much more emphasis should be placed on monitoring of lands and waters that are not directly involved in the development but that will be made accessible for recreational use. Also, the impacts of the construction workers should be carefully monitored. Obviously the whole question of indian values and resource utilization needs to be looked at much more carefully.

Throughout the workshop, participants were asked to compare information requirements of the model to the data gathering plans that have already been formulated for the LeGrande area. In general, we concluded that the plans as currently formulated for intensive surveys and environmental monitoring would contribute very little to future management models, even though data gathering for eventual systems analysis is considered by Environment Canada to be a central goal in the James Bay Area. It is hard to imagine how effective management decisions about the James Bay Area can be made without answers to some of the questions that arose during the development of the model described above, and it is clear that those questions will not be answered by the impact studies now planned. We have as yet no way to assess whether or not this point will be remembered by the workshop participants, some of whom will be making decisions about allocation of research effort in the next few years. A workshop wrap-up session was held to sound out participants about what they had learned, but the results were inconclusive. Many participants were enthused, but others felt that their own study plans had been made to seem foolish or irrelevant. In the defense of empires, rational thinking is often put aside.

DISCUSSION

Obviously most of the parameter estimates used in the two models were pure guesses; in many cases better estimates simply do not exist, especially those related to recreational demand. Simulation models in resource management are often open to this criticism, and typically the conclusion is drawn that modelling is premature. The James Bay exercise points out very nicely the fallacy of this conclusion; given current direction of research and monitoring effort, the appropriate data would never be collected. We tend to forget that all data collection is guided by some model of nature; workshops and other exercises only try to bring this model out into the open so that its basic assumptions can be examined objectively.

A central problem that we have not touched in discussing either of the models above is validation. Both models deal with long range predictions that we cannot hope to test with a few years of monitoring data or with any carefully planned experiment. It might be possible to validate (or reject and replace) some of the submodels, but the major prediction errors will probably be due to factors and system components that have not been considered at all. For example, a whole new set of problems in small watershed management could arise if economic factors permit a major shift in forest practice from rotation logging to intensive tree farming. The point is that resource model predictions are usually conditional on the assumption that social and economic factors which determine resource demand will not change in the future; since this assumption is not reasonable, it is absurd to demand that any resource model have absolute predictive power.

Why develop resource models at all, if validation is impossible and if any long range predictions are almost sure to go wrong? Most participants in our modelling workshops have felt that the exercises were worthwhile; have they been deluding themselves? The best answer to these questions appears to be that resource models must be judged relative to one another and against intuitive decision making paradigms. We must somehow make decisions about resource problems, so some model is always going to be used; we need only ask whether it is worthwhile to make this model explicit. Validation questions should not be couched in the form "Is this model correct?"; rather, we should ask "Is this model more likely to give correct answers than any alternative which we can now envision and implement?".

During the Silt Creek and James Bay workshops, we faced some serious technical problems for which we were not able to provide adequate answers and which forced us in many cases to be more simple minded than was necessary considering available data. Most of these problems are related to the limited speed and capacity of electronic computers in handling discrete representation of phenomena that occur more or less continuously in time and space. We were not able, for example, to provide a really clear picture of impacts on the small lakes and streams that may be very important for recreation in the James Bay Area; all of these waters within each large land unit were considered to be equally accessible and productive. In the Silt Creek model, we might have obtained much better estimates of pollutant transport rates by considering water flow variations associated with each storm event, since the short peak flow periods are critical for material transport; obviously this would require much more computation time. There do not as yet exist any objective criteria for deciding how much spatial and temporal resolution is necessary in particular models, since simplification can lead to a variety of different kinds of errors. The only suggestion that can now be made is that the model builder should not rely on a single representation of any system; several alternative schemes should be tried, and the results compared for error patterns.

The Silt Creek and James Bay exercises strongly suggest that the major information need for watershed management modelling is not associated with any of the traditional resource disciplines. We can muddle along with existing understanding about hydrology, forestry, fisheries and wildlife; where the models really fail is in representation of demands for resource use. Too often fisheries and wildlife investigators assume either that the animals can take care of themselves, provided that habitat conditions are maintained, or that demand will automatically adjust to whatever conditions of abundance prevail. Likewise, little is known about non-consumptive demand for wildland resources and about demands for recreational cabins and lots.

It is very easy to criticize many simulation models in ecology on the basis that they contain only figments of the imagination of the model builder, who often has only a superficial understanding of the system that he is trying to describe. We believe that the workshop approach, by making possible a more intimate feedback between model and subject matter expert, has helped to alleviate this problem in the models described above. The assumptions and functional relationships in each seem to capture (and in some cases go beyond) the basic state of understanding in the disciplines concerned, though we could certainly go back and considerably elaborate each submodel. However, it hardly seems worthwhile to spend time on more elaborate models, considering the major information gaps that even the simple models described above have helped to identify.

APPENDIX VIII

A Conceptual Framework for a Strategy to Mobilize Ecology and Other Sciences in Order to Solve Major Problems Related to Fisheries

H. Regier

Introduction: Planning and Strategy

In Canada, as elsewhere in the Western World, the era in which laissez-faire free enterprise was the primary political stimulus has come to an end. We are apparently well into a period of extensive cultural instability and of massive institutional transformation which will predictably extend several decades into the future. The implicit hope is that major transformations can occur by stages, that neither bloody revolutionary anarchy nor rigid state autocracy are necessary to effect the transformations, and that intense trauma to any major group of citizens and major social institutions can be averted without crippling the transformation process. All major political parties now recognize the need to perceive the nature of major social processes and to plan accordingly.

Planning mechanisms are developing at all levels within a hierarchy of political units defined geographically, i.e. global, regional-international, national, regional-national provincial, regional-provincial, metropolitan and municipal. Within these levels major planning emphases have to date been focussed at the national, provincial and metropolitan levels, but at other levels is developing rapidly. Much of the interfacing between levels is still unstructured, i.e. it is haphazard, ad hoc, and relatively unplanned.

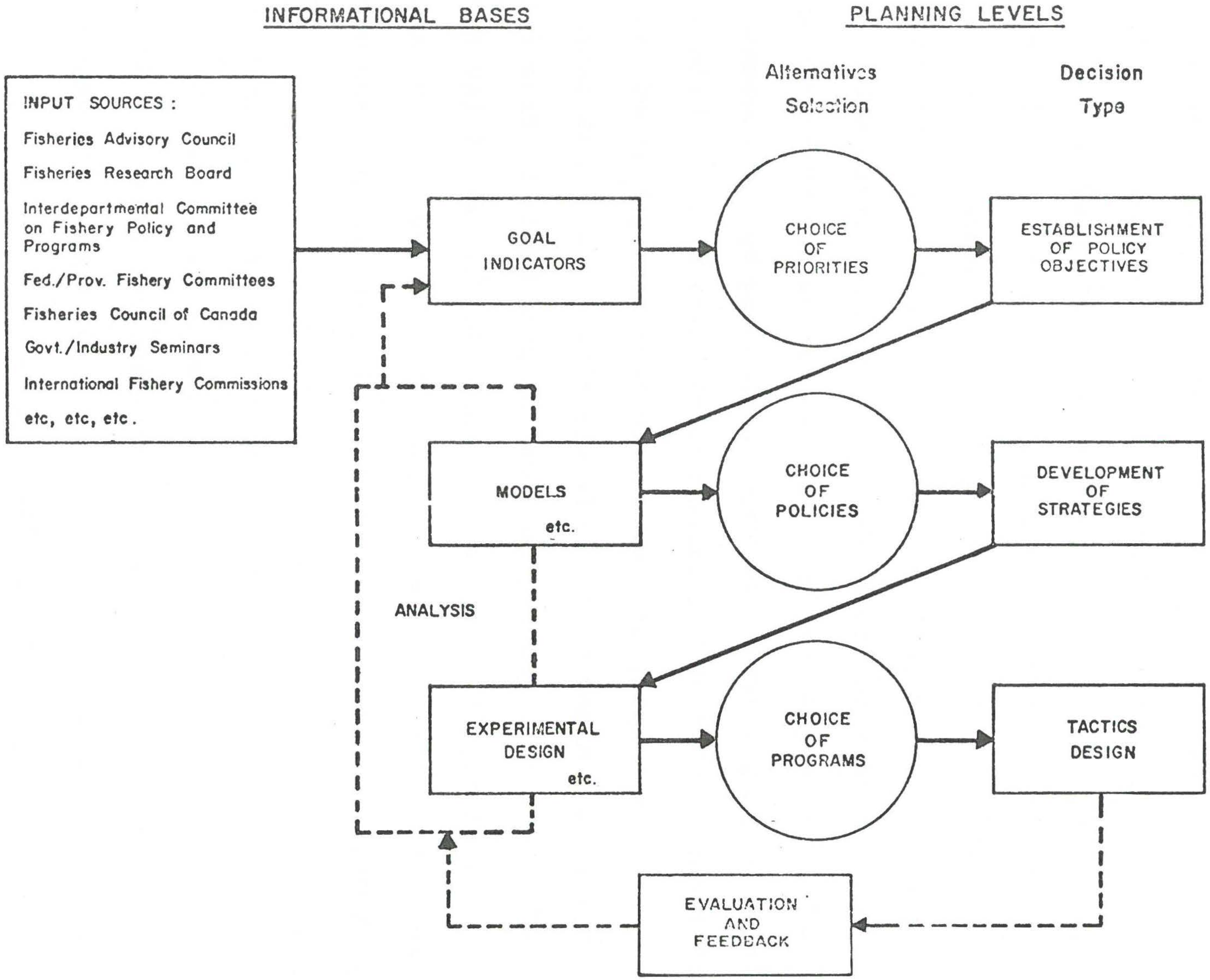
Within a particular political unit there exists a further institutional hierarchy, and there also the planning process is tending to organize itself in a three-tiered structure.

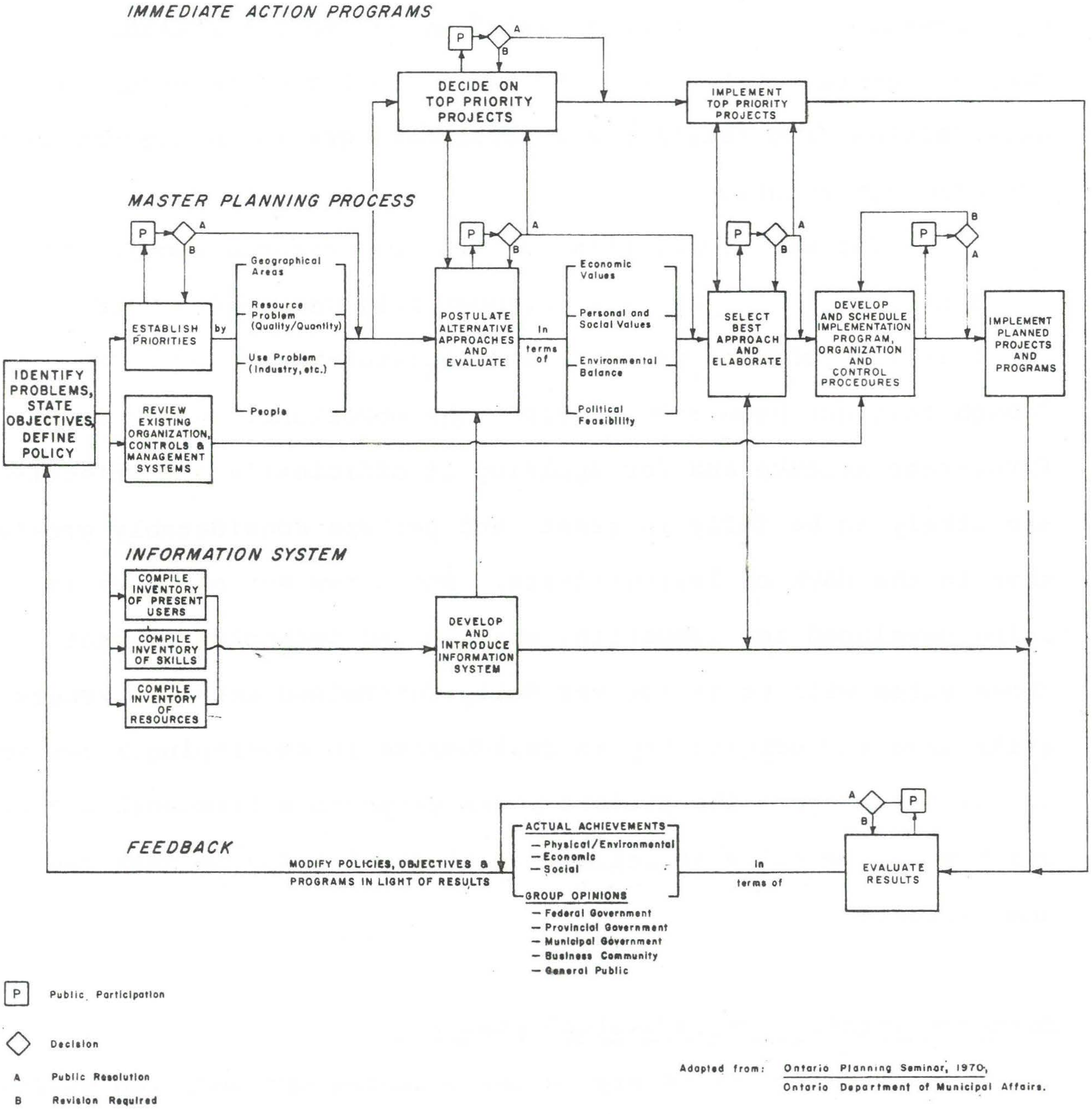
Politicians, particularly within the party and cabinet, consider major goals, alternatives, capabilities, and then set priorities. The "mandarinate" or senior level of the civil service identifies and formulates major strategic or policy alternatives for cabinet action. The directorate or mid-level of the civil service plans program and project alternatives for decision by the mandarinate. Each of these three levels seeks to engage responsible and knowledgeable persons within non-governmental organizations in the relevant planning process. As this three-tiered institutional process appears now to be developing within Canada's Fisheries and Marine Service has been analyzed by MacKenzie (1973) who referred in particular to work on planning by the Economic Council of Canada (1971) and on fisheries planning by Rothschild (1973).

A variety of flow charts have been published that suggest how planning might proceed efficiently. Figure 1 is taken from MacKenzie (1973) and Figure 2 was adapted by I. S. Fraser (see Regier, et al, 1973). Figure 1 more clearly identifies the tiered structure, Figure 2 depicts some of the finer details, particularly among the interactions between levels, and with the public or non-governmental organizations.

One of the consequences of the widespread transformation from a laissez-faire to a more planned approach is that science-technology as well as scientists-technologists are being mobilized and integrated into the ordered, tiered, cyclical planning and decision-making process. One of the events in this mobilization was that research and researchers within the fisheries and marine components of the Canadian federal government were

Figure 1. The Decision-making Process developing within Canada's Fisheries and Marine Service





Adapted from: Ontario Planning Seminar, 1970, Ontario Department of Municipal Affairs.

Figure 2. Resources Planning as a dynamic process. Incorporating a possible public response system.

integrated into the hierarchic line-management mechanism, and the semi-autonomous Fisheries Research Board lost its authority over research and has been assigned an advisory function. A second feature relates to a change in funding of research in universities from relatively unrestricted grants to negotiated research agreements.

The mobilization-integration of research appears to be an irreversible step in an irreversible movement toward explicitly structured planning and decision-making procedures. Though this has been much decried, the opportunities for doing first-rate science and for applying it efficiently and effectively are likely to be fully as great, and perhaps considerably greater, than in the days of laissez-faire. But a new set of rules is being developed for supporting science and technology. What those rules will be is not yet fully determined and researchers still have the opportunity to collaborate in developing rules to mutual advantage. The present paper proposes a framework within which possible rules or scientific strategies may be analyzed and evaluated.

Research within Applied Systems Analysis

Research necessary in the planning and decision making process sketched in the preceding section can and will occur at very different levels of generality, which again may be viewed in a hierarchic structure. Thus the entire process depicted in Figure 2 as it operates in practice may be the subject of scientific analysis in order to improve its efficiency or to measure its usefulness, in comparison to an alternative process. Though this kind of research may well be relevant to strategic planning, i.e. to responsibilities within the terms of reference of the mandarinate, it will not be considered further here, - for lack of competence on my part.

A second lower level of generality addresses the question of which traditional disciplines to co-opt with respect to already identified, major classes of problems, which scientific traditions within various disciplines to develop further, which traditions and disciplines to induce to fuse, whether new traditions might be created, how the research corps of an agency should be balanced with respect to disciplines, traditions, special technical competence, etc. This paper is addressed particularly to questions at this level of generality, which is here viewed as relating to concerns of the mandarinate, as well.

A third level of research, integrated within the problem-solving process which Raiffa (1973) calls "applied systems analysis" or ASA, relates more closely to the concerns of the directorate levels. It may be viewed as a microcosm within the broader process sketched in Figures 1 and 2, particularly as nested within the lowest level of Figure 1. Excerpts from Raiffa follow.

"ASA...involves the use of techniques, concepts and a scientific, systematic approach to the solution of complex problems. It is a framework of thought designed to help decision makers choose a desirable (or in some cases a "best") course of action. The approach may entail such steps as:

(a) recognizing the existence of a problem or a constellation of interconnected problems worthy of and amenable to analysis;

(b) defining and bounding the extent of the problem area. It is necessary on the one hand to simplify the problems to the point of analytic tractability and on the other to preserve all vital aspects affected by various possible solutions. The difficult judgement upon the inclusion or exclusion of problem elements - balancing their relevance to the analytical grasp of the situation against their contributions to unmanageable complication - often determines the success of systems research;

(c) identifying a hierarchy of goals and objectives and examining value tradeoffs;

(d) creatively generating appropriate alternatives for examination;

(e) modelling the ... interrelationships among various facets of the problem, ...;

(f) evaluating the potential courses of action and investigating the sensitivity of the results to the assumptions made and to facets of the problem excluded from the formal analysis;

(g) implementing the results of the analysis.

Precisely because ASA is a rational approach rather than a technique, the list of steps above should be understood in a qualified sense. Not all the steps need be included in every instance of responsible system analysis. Some steps may be handled in a more formal manner than others": etc.

So far, Raiffa. Actual experience in perfoming applied systems analysis according to this model (in essence) has been summarized and analyzed by Holling and Chambers (1973). Within Canada's Fisheries and Marine Service two projects of this type are now in the planning stage: the Straits of Georgia Project and the Gulf of St. Lawrence Project. Canada's plans within the Man and the Biosphere Program (MAB), are essentially of an ASA nature.

I reiterate that the details of identification and solving of actual problems, within the natural resources field, using ASA is not the primary concern of this paper. To what extent ASA should be stimulated and supported, and how various stimuli might be applied and modulated, are relevant to the strategic or policy levels of decision making. Appropriate guidelines on these questions will emerge iteratively as a result of experience and evaluation within successive cycles of the larger process depicted in Figure 1.

Problem Complexity

As indicated by Raiffa (see above) not all problems are equally difficult. Some screening mechanism may be conceived that would help to sort problems objectively into different classes of difficulty. Or a number of screens that are conceptually orthogonal or independent might be used to sort problems into a 2- or 3- dimensional ordering, if this is seen to be useful within the broader process. The development of such a mechanism, and servicing to ensure its proper functioning, might be a strategic responsibility.

Cartwright (1973) has produced a context that neatly interrelates problem complexity, research challenges, and likely limits of action, in the short-term (Table 1). Raiffa's full description of ASA appears to relate to what is termed a "metaproblem" by Cartwright. But Raiffa does imply that less difficult problems may not require the full gamut of formal ASA steps. Clearly the scope and major components of the operation to be mounted in studying a particular problem is an important decision, and Cartwright's formulation may be useful in approaching such a decision objectively.

Scope and Scale

Within any ordered, cyclical research and decision-making process whether within ASA and solving problems in the field or within the context of Figure 1 where major institutional problems are solved - questions of scale and scope rapidly materialize. But they are seldom addressed explicitly, particularly within fisheries work. By scope I refer to the overall dimensions conceptually (and/or spatially and/or temporally) of the models employed in the research; scale refers to the relative magnitude of the units of measurement employed with particular variables included in the model - i.e. the inverse of the "degree of resolution" or precision. Paulik (1972) and Holling and Chambers (1973) have discussed aspects of this question.

Table 1. Limits of analysis and action by type of problem. (Modified from Cartwright, 1973)

Has an adequate model been developed?	Are all variables readily measurable?	Type of problem	Limits of analysis	Limits of action
Yes	Yes	1. Simple	Comprehensive and adequate in practice	Maximization or optimization
No	Yes*	2. Compound	In-depth analysis of parts of problem	Sub-optimization, "second best"
Yes	No	3. Complex	Broad, imprecise understanding	Overall improvements
No	No	4. Meta-problem	Identification of points of departure, set benchmarks	Partial improvements

* The question may be asked: how can it be know what are the relevant variables if an adequate model has not yet been developed? This is the old chicken-egg conundrum, to those that can only think dichotomously. Here a number of experts presumably can agree on a semi-structured model and share a consensus that it appears to be ready for orderly development.

Elaborating the point further, research models of particular components of a process may be of much greater scope and of grosser scale than is appropriate to the nature of the problem. Conversely relatively very delicate models or intricate assemblages of delicate models may be devised where something more robust is in fact required. Where models and problems are mismatched, research will eventually provide some useful information but at relatively high cost.

In fisheries work serious mismatches of model and problem are now the rule rather than the exception, although the mismatching is beginning to be recognized as such. In particular certain macro-problems[1] now facing Canada's fisheries scientists are by and large being addressed in terms of scientific micro-models. The following series of ten macro-problems may serve as a check-list to test the above contention.

1. Cooperatively with other disciplines, ecologists must devise effective management and regulatory guidelines for fishery exploitation to maximize economic rent or some other social index or indices. Most basically, the common property problem must be solved conceptually and in practice. This involves both "open access" and "multi-purpose" aspects. The scale and scope of the ecological models must be consistent

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[1] By "macro" I mean of large dimension conceptually; c.f. "meta" as used by Cartwright which refers to a large measure of complexity.

with those of the economists, sociologists, political scientists (re law, regulations, institutions), etc.

2. More particularly, extension of Canadian sovereignty to the edge of the continental slope will require that Canadians know how to manage a mix of interacting species resources being harvested by a mix of interacting fisheries interests. In the foreseeable future it will only be possible to model a minority of the fish species involved, à la population dynamics, - and then only where the various species interactions are "simple" as perceived in the population dynamics paradigm.

3. The "new frontier" of the oceans may well involve us in the classic frontier-type scramble for resources using the only technology available - which will be highly inefficient and will quite accidentally severely disrupt the life support systems of some of the fishery resources. Macro-models are needed to predict the likely impacts of this new example of a process now several hundred years old in North America.

4. Another new frontier, the North, poses similar demands for macro-models. This demand manifests itself in the call for "environmental impact assessments" for proposed major industrial developments. The difficulties being experienced at the present time in producing useful assessment relate in part to the fact that the ecologists involved are attempting to apply micro-models that are quite inadequate.

5. Fisheries ecologists have called for pollution abatement programs but have great difficulties predicting how the aquatic ecosystem, or the fish community component of it, will respond as pollution loading rates are reduced. Community indices or variables should be modelled as a function of loading rates by various nutrients, toxic materials, acids, etc.

6. Aquacultural initiatives are being encouraged, particularly in the inshore areas of the seas and estuaries, and in freshwater bodies. These habitats are highly vulnerable to stresses from conventional onshore practices - e.g. urban, industrial, or agricultural wastes; stream flow modification, port construction; etc. Also the inshore habitats, whether in salt, brackish or fresh waters, are of critical importance to a number of valued fish species. Clearly multi-disciplinary, macro-models are needed for inshore habitats.

7. Recreational uses and tourist industries will be expanded or intensified in remote areas, into the marine habitat, etc. If these enterprises are to benefit native peoples, existing fishermen, and other present users, as well as others in society, then a more effective and more comprehensive understanding is essential.

8. Urban complexes are growing and with them the inevitable, uncontrollable urban run-off problem. Fisheries ecologists will need to address themselves to the question where such urban complexes should be sited - a macro-problem.

9. Agriculture is becoming progressively more intensive - and will continue to do so for at least the next five decades. Already pesticides, fertilizer run-off, drainage from feed-lots, etc. are creating major problems for fisheries. Agriculturalists should be assisted to develop procedures to minimize impacts on aquatic systems - what is needed is an appropriate environmental impact model for each major agricultural option

10. Last - and also least, in our frontier culture - the desirability of preserving a series of native ecosystems in wild state in perpetuity requires a set of criteria, or a macro-model, of the ecological values associated with such a program.

We will come back to the question of alternative models in a following section titled "Scientific Traditions within Fisheries."

The question of appropriate scope can itself become complex. Emery (1973) has remarked that major practical problems - to be researched and resolved - may themselves arise from a serious mismatching of the scopes of two social processes both important to the decision maker. This may frequently be the case within fisheries. For example eutrophication may trigger a phase-change or transformation of an entire multi-species fish <u>community</u> while the harvesting, trade, and regulatory process remains geared to individual species populations or to closely related species groups. Pulse fishing and its consequences may be another case. According to Emery, the effective approach may be to organize the problem at the outset so as to fully encompass the largest unit of interest. This was in essence the perception and stimulus for our Symposium on Salmonid Communities in Oligotrophic Lakes of 1971 (lotus and Regier, 1972).

A Multidisciplinary Approach

Many of the problems now facing society, and fisheries workers, are of a scope and complexity such they they simply extend far beyond the bounds of any single scientific discipline (e.g. fisheries biology, economics, ecology, political science, law, etc). Within Kuhn's (1962) paradigm, it may be inevitable that any or all of these disciplines will and should cease a separate existence in order to amalgamate, to be extinguished, or perhaps to evolve into something qualitatively quite different. Though that is the long-term prospect, the short-term reality is quite different, perhaps because of the overpowering conservativeness of the universities in this respect.

The realistic option appears to be a rather coy liaison between two or more disciplines on problems of major social significance. But this liaison can take one of a number of forms, not all equally desirable or useful from the viewpoint of the matchmaker.

In the present context the objective of multidisciplinary collaboration is to solve important problems - hence problem-solving capability is what is desired. Such a capability (PSC) may be perceived as being a function of :

technical competence (TC) deriving from education, training, or past experience; existence of appropriate theory (AT) as a result of past work mostly by others in the discipline(s) of interest; and accessible data (AD) already in store or readily measurable <u>in situ</u>. Symbolically PSC = f(TC,AT,AD).

Almost all of our science is compartmentalized into "disciplines". Within a discipline there is generally some redundancy in that a number of "traditions" and/or "schools"[2] are implicitly encouraged, or at least tolerated, to develop and compete. Within a particular "school" and with respect to particular practical problems of special interest to a "school", TC, AT, and AD tend to evolve as a coordinated and mutually congruent set with respect to scope, scale, special techniques, model characteristics, etc.

Let us identify a particular discipline by the subscript i, and a tradition within a discipline as j. (Ignore the third tier in the hierarchy, i.e. "school" - it simply complicates the subscripting.) One strategy for generalized problem-solving would be to identify and select the most effective and efficient amont the PSC_{ij}. Symbolically:

$$\underset{i,\ j}{\text{select optimum}} \left(PSC_{ij} = f(TC,AT,AD)_{ij} \right)$$

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[2] These terms are defined and discussed further in a following section titled "Scientific Traditions Within Fisheries".

This results in selection of the best discipline-tradition combination for a particular job, i.e. a unidisciplinary approach.

Implicitly, the above approach has been used until recently in fisheries, and "fisheries biologists" of the locally dominant tradition have been assigned to solve any particular problem essentially alone. In water resource development in the U.S.A. during the early 1960's, cost-benefit analysts were the dominant tradition to the practical exclusion of others.

The multidisciplinary approach now being nurtured appears to rely on the existence of a number of traditions within each of a number of disciplines all of which are in some degree relevant to the practical problem. One or more traditions within each discipline, it is assumed, are conceptually congruent and of similar scope and scale to one or more traditions in some other disciplines, and to the problem of interest. The conceptually simplest case for the decision maker would occur when each discipline, i, would contain only one tradition, j, that was sufficiently congruent with only one tradition in each of the other disciplines and with the problem. Clearly if a multi-disciplinary approach would then be undertaken, there would only be one candidate interdisciplinary approach available for selection.

But suppose that there are a number of mutually congruent sets, each with a different contribution from each relevant discipline. Identify such interdisciplinary congruent sets by the subscript k. Then the strategy is to select

$$\underset{k}{\text{optimum}} \left(PSC_k = f(TC, AT, AD)_k \right)$$

The situation may in practice be more complex. With appropriate interdisciplinary or transdisciplinary education and training, technical competence may be interchangeable between disciplines and, of course, traditions. Also, available theories in different disciplines may be seen as being isomorphic, or variants of the same theory. Even accessible data may be mathematically transformed to be relevant within more than one discipline. This implies that a particular f(TC,AT,AD) as conventionally identified already contains parts that are readily interchangeable with other sets, with respect both to disciplines, i, and traditons, j. Under these circumstances the organizer selects

$$\underset{l,\ m,\ n}{\text{optimum}} \left(PSC_{lmn} = f(TC_l, AT_m, AD_n) \right)$$

Here the (l, m, n) set ultimately selected may or may not include a component from each discipline. But because of the general desirability of a measure of functional redundancy, it would seem a good practice to duplicate each of TC, AT, and AD, within a study of any major significance.

Again, the concerns of the mandarinate on this point need not extend beyond ensuring that in fact problems are being approached in an objective, explicit and defensible fashion. The details of the selection of appropriate problem solving capability for major field problems would presumably be the responsibility of the directorate level.

Isomorphisms

D.J. Rapport and J. Turner have for some years addressed the question of whether and to what degree theories and models already in use by some economists are in some sense analogous or homologous to those used by some ecologists. Some relevant comments by Rapport follow (see Regier, Bishop and Rapport, 1973):

"Natural communities of organisms as well as human societies fundamentally face similar problems with regard to resource use. Resources are limited in both communities and resources possess many alternative uses. Therefore allocation mechanisms are required to distribute resources to particular uses. In both communities there are rewards to the efficient user of resources, profits to the entrepeneurs who produce at low cost, higher reproductive rates to the species which can obtain resources with the least expenditure of energy. The payoffs to organisms can be represented by fitness sets; to economic man, by "indifference curve" maps...

"One of the many problems confronting those planning for the rational preservation of our planet is the lack of communication between those whose concerns lie with economic (growth) well-being and those who strive for our ecological well-being... A transdisciplinary framework for resource allocation could permit insight into both economic and ecological community functions. A common language ... might be developed so that theoretical structures which exist in one area would be readily transferred to the other. Such a framework would simplify knowledge by condensing theories which are currently stated in terms of specific languages to a theory which can be stated in a single language ... thus (joining) two disciplines which have thus far evolved on separate paths. This would then permit considerably more effective feedback among theory, monitoring and policy".

Similarly, attempts have been made to bridge ecology and sociology (see e.g. Emery and Trist, 1973), ecology, thermodynamics and economics (see Georgescu-Roegen,1971), and others.

Progress as a result of efforts to identify conceptual isomorphisms and to condense scientific theory and methodology should be of some strategic interest to government. Communication can be simplified and made much more efficient, multi-disciplinary problem-solving teams need not be as large as would otherwise be the case - in general costs would be reduced.

An Environmental Macro-Discipline

In a Toronto speech in March, 1973, Ian McHarg identified a mutually compatible set of disciplines and traditions related to environmental concerns and problems. These are: ecology, ethology, ethnology, certain traditions within human geography, or ethnography aspects of cultural anthropology, and epidimiology. Following Rapport (see above), certain traditions within economics might also be compatible to this set, - see e.g. works by K. Boulding and perhaps J. K. Galbraith.

Individually and as a set the disciplines identified above tend to treat man and environment as mutually interdependent, but from a higher-level viewpoint. None is bounded by an artificial man-environment interface.

Efforts to create a new or macro-discipline to encompass all of these units - now widely scattered within social institutions such as the universities, the professions and government - might now be timely. This would be of strategic interest. Marshalling teams from among this set for practical problems might remain a tactical-level responsibility to be addressed by the directorate.

To practical people such as engineers, physicians, lawyers, cost-benefit analysts, systems analysts, planners, and administrators there need be no threat in the above suggestion. Quite the reverse! The intention is to provide broader, more encompassing and hence more useful models in order that decision-make fulfil their responsibilities more effectively at less cost to themselves and their employers.

The present section is based in part on the paper by Regier, Bishop and Rapport (1973). That paper also contains a critical examination of the artificial man-environment dichotomy inherent in our culture and its counter-productive implications from the viewpoint of our responsibilities with renewable natural resources and the ecological environment.

Technical Sophistication

Several of the preceding sections have dealt primarily with the question of available theory; this section addresses aspects of technical competence and some facets of experimental design and sampling theory as related in essence to the intensity of the man-environment interaction. The section is based on work by Regier et. al. (1973) as restated by Regier, Bishop and Rapport (1973).

By and large ecology has developed through time approximately as shown in Figure 3. Perhaps because the overall trend was largely uncharted and unplanned, the process has been quite uneven among different traditions of ecology, broadly, defined, such as meteorology, fisheries, forestry, hydrology, etc.

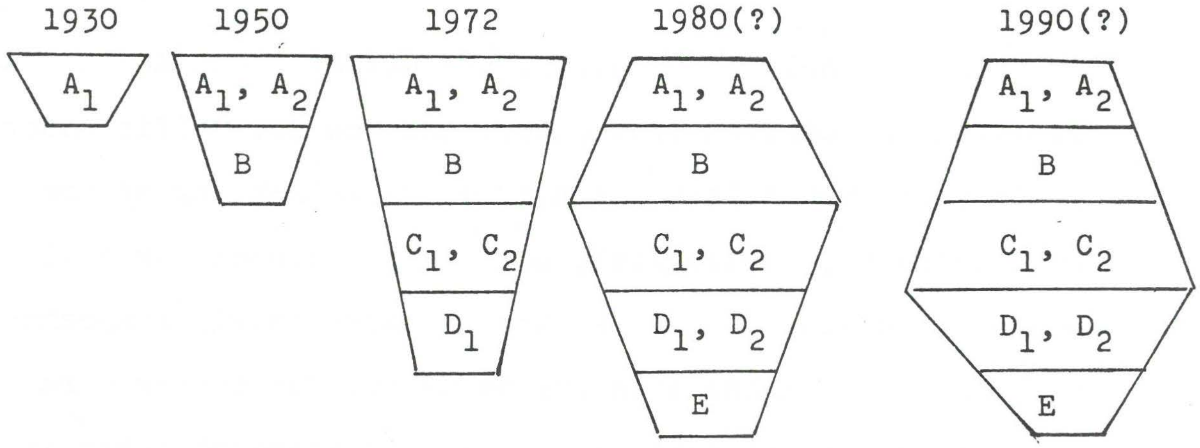

Figure 3. The size of the various strata is a very approximate of the effort (corresponding roughly to the cost to Canada) expended in collecting, processing, and applying corresponding data classes.

The symbols used in Figure 3 are defined as follows:

A_1: An inventory survey, undertaken by workers in a particular narrow discipline. A few factors and quantities are measured on selected sites over a broad area. Development of specific resources may be initiated on the basis of such data.

A_2: Assessments of the potential of natural resources, whether renewable or non-renewable, or of skilled manpower, etc.. This step is used in early stages of planning developments that required large social and/or capital investment; and in regulating resource use.

B : Assessments of the likely environmental impact of proposed large-scale developments. "Impact statements" are used in simplified socio-economic planning, e.g. in applying cost-benefit procedures.

C_1: Routine monitoring of indices, the mathematical definitions of which are derived from experience and scientific theories, of factors that relate closely to the well-being of society from cultural, ideological, political, economic or environmental viewpoints. Indices that measure fairly comprehensive factors over a broad area may be useful for longer term projective/extrapolatory planning by government agencies.

C_2: Process monitoring and real-time control of some particular, important man-resource interactions such as the off-loading of noxious wastes or the harvesting of certain sensitive renewable resources. This approach tends to forestall overly intense stresses being applied within intensely interactive situations.

D_1: Step-wise, experimental management in which an explicitly formulated decision process uses information from past management experiences and experiments, together with measurements of indices routinely monitored, to guide future management.

D_2: Formal functional analyses of components of man-resource problems as dynamic systems. Usually a number of disciplines collaborate. This phase is still largely experimental.

E : Integrated planning and decision making using formal analyses of policy alternatives performed as much as possible in a transdisciplinary context. A few trials have been begun in Canada in man-resource problems.

The trends sketched in Figure 3 have the following six implications:

- From early stages of economic development, where questions of resource potential and unpleasant aspects of the natural environment predominate, the data requirements have gradually shifted to what is needed to understand, order and manage man's demands and impacts on certain resources and the environment.

- Single factor, simple resource and separate discipline conceptualizations are eventually displaced by multidisciplinary and finally transdisciplinary approaches.

- Inventories of relatively static resources lead eventually to predictions on complex interactions using functional analyses of dynamic man-resource systems.

- Elementary scientific and technical methods appropriate at early stages are superseded by highly sophisticated and complex precisely-ordered procedures, together with higher-levels of concept coordination.

- Simple records stored in survey notebooks are eventually succeeded by data systems in a national network of electronic computers.

- The more highly a region is developed in a conventional "economic" sense, the more intense the man-resource and the man-environment interactions are likely to be, and the further along in the direction of sophisticated transdisciplinary procedures will the technical data process need to be developed.

Figure 3 may be used as an approximate standard by which to judge the present state of the information-analysis-planning complex for certain major components of our man-environment problems.

  - Level A methods should be extended to cover all of Canada with respect to some factors and resources.
  - Level B should be applied to all new developments.
  - Level C methods should be expanded to greater parts of the more developed areas, and more types of information should be obtained in this manner.
  - Level D approaches should be used more widely and facilities for the necessary technical training expanded.
  - Level E research should be encouraged in a number of appropriately sophisticated university contexts across the country.

It should be emphasized that the techniques under Level E should be developed to use "citizen input" as well as traditional "scientific" data.

Alternatives among Scientific Traditions Relevant to Fisheries Problems

Elsewhere (Regier, 1974b) I have expanded at length on the question of how different types of major problems facing fisheries as harvesting and management processes should be addressed within different scientific traditions that already exist within the set of disciplines related to natural resource ecology and management.

A two-dimensional classification of existing and perceived problems is presented in Figure 4. The two basic criteria of stratification are mean and variance, where the latter refers to temporal oscillations or fluctuations. For each of the four classes in Figure 4 there already exists a number of alternative scientific and practical models and methods within the natural resource family of disciplines. Some have not yet been adapted to fisheries situations, but this could be done expeditiously given an appropriate stimulus.

Further details and suggestions were elaborated by Regier (1974b). It seems clear that the "population dynamics tradition" - conventionally the dominant and sometimes sole tradition applied to a particular fisheries problem - is really only effective and efficient with Class A situations. This class may now include considerably less than half the situations in which major problems are emerging within world fisheries. If so, it should be of strategic concern that effective scientific models and methods be adapted and refined for classes B, C, and D - without sacrificing the necessary emphasis on Class A approaches where these remain appropriate. Perhaps the first priority would be to systematically search out appropriate approaches in related disciplines and adapt them to fisheries situations. The stimulus from such an exercise might fortuitously result in the creation of novel approaches - if so, so much the better. But much can be accomplished

HIGH

↑ TEMPORAL AND/OR SPATIAL FLUCTUATION IN BIOMASS COMPONENTS ↓

Class D: Many small resources interacting within systems that are fluctuating due to pronounced non-constant natural and/or cultural stresses. Variability may be modelled as an "independent" variable within a set of similar systems. A major objective of management is to prevent the exploitation-regime from developing a positive feedback interaction with other stresses, using a step-wise experimental approach. Examples: intensely exploited, polluted, fluctuating systems such as Great Lakes, Baltic Sea, some estuaries and bays.

Class B: A few large resources dominate; they fluctuate markedly- and consequently interact - as a result of large-scale non-cyclic stimuli related to climate, oceanographic processes, the fishery, etc. Monitoring, Markov-like modelling, and probabilistic forecasting may be used to plan industrial activities so as to compensate for variability, and perhaps to develop negative feedback mechanisms to control variability. Examples: clupeids, flood plain fisheries.

SMALL ← SIZE OF INDIVIDUAL SPECIES RESOURCES OR STOCKS → LARGE

Class C: Numerous small resources usually interacting ecologically in systems that are likely to remain relatively unstressed or that possess capabilities to accommodate expected stresses. Yield in toto or by taxon--groups may be modelled as a function of large-scale natural and cultural variables; management may be explicitly experimental and step-wise. Examples: mixed resources in lakes, large reservoirs, near shore in seas, on reefs.

Class A: Several large stocks that are relatively independent ecologically dominate the ecosystem in which biomass components are quite constant and/or relatively unresponsive to moderate stimuli. Resource use may be optimized separately stock by stock using population dynamics techniques. Examples: marine benthic taxa, tuna, whales, anadromous salmonines.

LOW

Figure 4. A conceptual model of four major clusters of problems related to fisheries exploitation, with identification of a scientific tradition particularly relevant to each.

without any further basic innovations. In other words, the work of identifying and developing further a number of alternative approaches for each of the four classes in Figure 4 can now be planned, costed and programmed quite objectively.

A preliminary examination of social, political and economic (industry and trade) features associated with problem classes A to D suggested that they too could be usefully stratified in this manner. If so, then this would be an instance of a large-scale isomorphism, across disciplines, and would provide useful cues on how multi-disciplinary teams might be structured for major problem classes. Thus - risking over-simplification - four classes of multi-disciplinary teams might effectively cover all the major problem types with "conventional" exploitation and management. Not just any multi-disciplinary assortment - even within the constraints specified in the section on "Multi-Disciplinary Approach" above - will do. But four (and only four) different teams, suitably organized perhaps as implied in Figure 4, may be sufficient. Thus some specialization might be possible and also desirable.

A further isomorphism may be of interest. At present, and from the vantage point of the population dynamics tradition, problem classes A to D correspond in sequence to Cartwright's problem types 1 to 4 described in Table 1 above. But given appropriate models, each of classes A to D can in theory be reduced to a type 1 problem. At least that is the hope.

I hasten to add that no problem is ever settled permanently from the viewpoint of Kuhn (1962) as elaborated by Grabow and Heskin (1973), Emery and Trist (1973) and others. Rather it can be solved, for the time being, within the conventional paradigm, or even more specifically within the present temporal Gestalt and institutional arrangement.

Ecological Levels of Organization

Rather closely related to the discussion in the preceding section is the matter of the ecological level-of-organization at which a problem should be addressed. Three tiers have come to be accepted in ecology as in some sense "natural" hierarchic nodes - whatever that may mean. Those three levels are: whole organism, species population or stock, ecosystem. (I rather favour an additional level - a "community" of taxa that are fairly closely related within the evolutionary paradigm, and are generally also closely related ecologically; see Loftus and Regier, 1972. But this intermediate level between population and ecosystem may be ignored for purposes of this paper.)

If the discussion of scope and scale above, and also particularly that in the preceding section are seen to touch on useful concepts, then the matter of ecological level-of-organization may be seen as simply an elaboration of those points. Thus class A problems in Figure 4 are likely to be mose usefully addressed at the population level, class D at the ecosystem (or community) level.

Elsewhere (Regier 1974a) I have reviewed the present status with respect to fisheries interests of the science of whole-organism ecology (autecology, physiological ecology, physical factors ecology, etc.), population ecology (population dynamics, population genetics, "natural history", etc.), and ecosystem ecology (succession theory, stress responses, stability, etc.). An explicit stratification might well contribute to more useful strategic planning, particularly in that universities may be induced to balance their undergraduate and graduate programs in this respect. Because universities tend now to work within this context, rather than that depicted in Figure 4 or any of the preceding discussion, and because of their conservativeness will continue to do so for some time, selection of new personnel for mission-oriented research may be improved by noting the manner in which competence in the ecology of a particular level of ecological organization relates to a class of practical problems.

Interactions Between Universities and Government Agencies

P.L. Bishop has suggested the model and dynamic depicted in Figures 5 and 6 as appropriate for discussion for interactions between such institutions as universities plus research organizations and action-oriented agencies (see Regier, Bishop and Rapport, 1973).

Figures 5 and 6 may be self-explanatory. It may, however, be useful to point out that the two dimensions of the paradigm are knowledge and institution. The institution dimension is defined with gradient limits, which move from mission- or action-orientation to speculation or theory. Similarly, knowledge is defined on a gradient from use or application to elaboration or further development. Through such knowledge-institution definition, one is able to focus on major phases in the management of large scale problems in man-environment interfaces. Analysis, always based on a theoretical construct, is then given a control or positive feedback correlate by means of theory in analysis. In turn, theory in analysis is controlled by theory in intervention (strategy), and theory in intervention by intervention. The processs can be further iterated by emphasizing actual intervention as it relates to operational analysis, achieving a "spiral" effect which results in policy.

In summary, one can achieve not only activity foci but also organizing principles (higher level coordination) for those activities. By the introduction of transdisciplinary links between organizational (institution) contexts and scientific (knowledge) activities, a two level coordination of terms, concepts and principles results. The contexts move through analysis and its theory, through theory (science) and its strategy, strategy (theory in intervention) and its intervention, and finally, these contexts spiral through interactions back through analysis, theory and strategy, which results in policy.

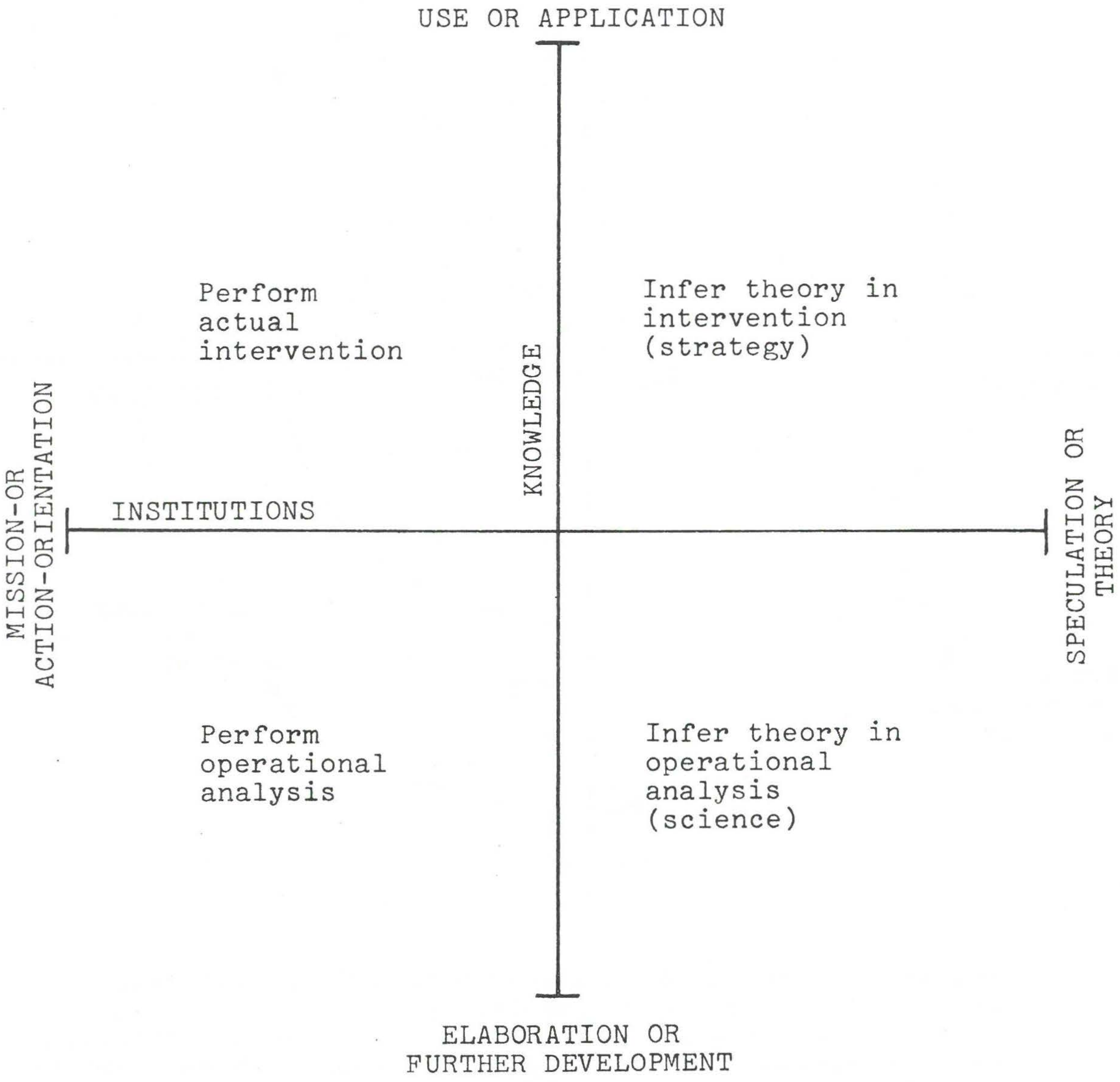

Figure 5. The quadrants identify four major types of complementary activities that may result from effective use of knowledge by institutions.

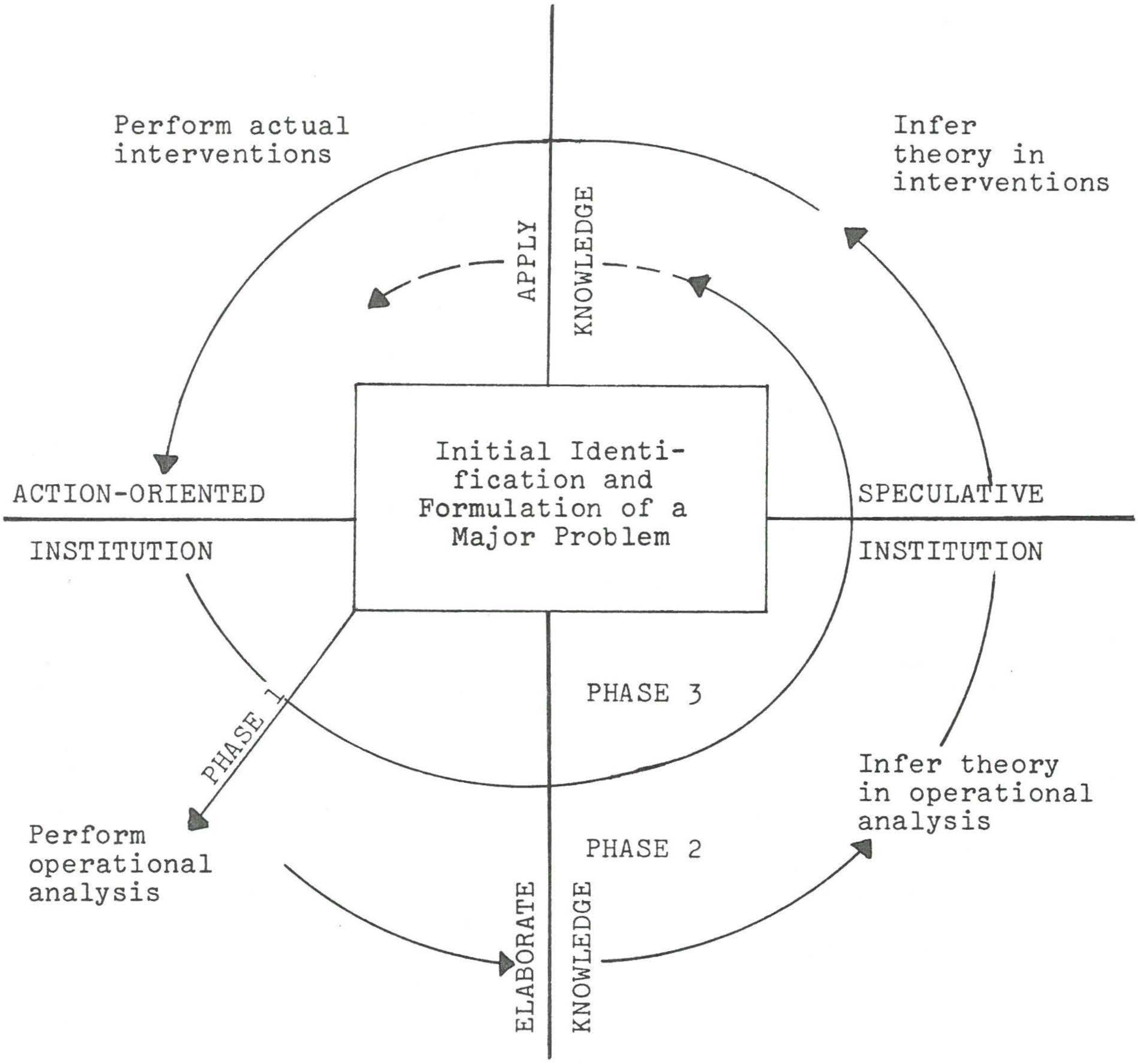

Figure 6. The phase sequence of institution-knowledge interactions that will likely occur, implicitly or explicitly, in the course of solving a major problem. The overall paradigm will be man-environment interrelatedness. Phase 1 may be termed formalization; the phase 2 circuit is research iteration through experimental intervention; phase 3 leads to policy articulation and routine program delivery

Implicit in Figures 5 and 6 is the dictum commonly heard that vertically-organized structures are efficient for solving perceivedproblems, and loosely co-ordinated horizontal networks work best for developing scientific inferences and theories. A third dimension might be added - perceptions are likely to emerge and be clarified within the public and the politicians beyond the decision-making process and the research network. Hence the necessity for advisory councils and citizen participation to interact particularly with the "action-oriented institution". To the extent that the subject matter of Figure 6 is largely within the domain of the social science disciplines, social science researchers might well mediate between all three: decision-makers, researchers and public advisors.

Emery (1973) makes the point that if social scientists seek only to study the process, they will inevitably influence it; hence they might approach the issue at the outset as one of mediation. But the responsibilities are great, and the process demands an explicit higher level conceptualization - perhaps a credo - that other actors in the process may recognize and take into account.

Recapitulating, an action-oriented institution will not long remain effective, - even if it has mobilized a corps of researchers to attack important questions - unless a loosely co-ordinated network of robust and relatively independent researchers exists and is accessible, and unless a balanced corps of knowledgeable public advisors make available its insights to the agency.

Some redundancy will exist, but functional redundancy may be a most important property tending to ensure desirable evolution, relative, stability, orderly and manageable response patterns, and a healthy resilience.

International Transfer of Science and Technology

Scientific and technical information developed in other countries is transferred to Canada to our advantage (Science Council of Canada Report No. 20). Clearly this is an item of strategic interest and deserves explicit recognition, study, planning, and management. In Canada the Ministry of State of Science and Technology is now developing procedures to oversee and regulate aspects of this process, and the interests of fisheries deserve fair consideration.

Fisheries conflicts have in the past led to international violence and may well do so in the future. The Law of the Sea process is seeking to develop conventions to forestall such events. Perhaps equally important, international organizations of scientists are forming to study problems jointly and to develop common approaches toward and understanding of difficult problems.

The International Institute of Applied Systems Analysis located at Laxenburg, Austria, is a recent creation and joins a large constellation of other international institutions that perform a similar function plus other functions (e.g. FAO, UNESCO, WMO, ICSU, IUCN, etc., plus various derivative groups). Closer to home, numerous Canadians and some Canadian universities are associated with the Institute of Ecology (TIE), an international institute with headquarters in Madison Wisconsin. TIE objectives and programs are of particular **relevance** to strategic planning within Environment Canada, for example. The number of committees, working parties, seminars, etc, has proliferated to the point that a medium power such as Canada cannot hope to participate in all. Whether a screening mechanism could be devised to sort out those of particular interest to Canada should be considered.

Mobilization

As indicated early in this paper, researchers and other classes of professionals are gradually being mobilized into more explicit and disciplined institutional structures and problem-solving processes. With respect to ecologists, this is partly a consequence of the success of their campaign to alert the public and politicians to their concerns, and also of their clamoring for a greater role in planning and decision making to help rectify past mistakes and prevent major future catastrophes. If a crisis threatens we do mobilize and forego some freedom temporarily in order to prevent a more massive and more permanent loss of freedom which would follow if the mobilization did not occur.

But in general the present mobilization appears to be the result of other processes as well, those related to post-industrialism, anti-consumerism, anti-opportunism, etc.

If the more pessimistic ecologists are correct in their assessment of the future, then mobilization will expand and intensify. Clearly this prospect deserves very close study. As with mobilization for war, it seems likely that the first casulties of the actual process will be freedom and truth, at least if a really major crisis threatens. Thus mobilization, even with the best intentions, may pave the way to hell.

The mobilization is now occurring concurrently in a number of ways. Thus researchers within the Fisheries and Marine Service have been in part integrated into problem-solving units. In universities, grants from Ford Foundation, Fisheries Research Board, National Research Council with respect to the International Biological Program, etc., have led to the formation of voluntary, semi-disciplined teams. The Man and the Biosphere Program plans to develop disciplined teams that will include personnel from universities, a number of government agencies, and perhaps private organizations. Among the "public," such groupings as the Fisheries Advisory Council, Environmental Council, and civic groups such as Pollution Probe, SPEC, STOP, etc., are developing strong structures and exerting major forces.

The nature of this semi-integrated system now developing needs careful study, and alternatives should be considered. From the viewpoint of science, it seems clear that most major advances will emerge within the loosely co-ordinated network. But it seems equally clear that problem-solving should be vertically organized. The interfacing between these two major groups needs particular attention - at present there is little if any understanding, planning, or management of this interfacing process.

Perhaps the Fisheries and Marine Service should stratify its researchers into three groups - program directed, mission-oriented, and undirected. The latter would perhaps be the "senior scientist" type, likely to innovate to the long term advantage of society. The mission-oriented group might interface four groups - the undirected, the program directed, the outside network in Canada, and foreign workers, The mission-oriented scientists would review, synthesize, integrate, interpret, for the benefit of both problem solvers and scientists. Associated with them should be some scientific writers to communicate with laymen and the public. Thirdly the program directed workers would in the future frequently work with an explicit applied systems analysis approach. The fact that such an approach is explicit, rational and adjustable from within as well as from without would tend to guarantee that creativity of the researcher would have scoped in which to operate.

LIMITS TO MOBILIZATION

The science of today exhibits in general a form of radical agnosticism. Grabow and Heskin (1973) have abstracted one formulation of the current scientific world-view as follows:

"See Thomas Kuhn's description of the rise and fall of scientific paradigms in his The Structure of Scientific Revolutions (1962). He traces the emergence and inevitable disintegration of competing explanations of the perceived universe; the competition for attention among alternate views; the arrival of consensus upon one view; the articulation and extension of that view to cover all perceptions of reality; the emergence of a phenomenon which calls the view into question; and the crises in which alternate views again compete for attention to resolve the anomaly. It is by calling into question the principles of validation by which consensus comes about, as well as articulating the inevitability of the cycle, that Kuhn effects a profound loss of innocence".

In that they perceive this process to be gradual, long-term and perhaps uncontrollable, - if they perceive it at all -, the great majority of scientists ignore it. They are content to work within the present time stanza, or the present temporal Gestalt, in which the horizon extends a decade or two into the past and half a decade into the future. But we are now part-way into a period of intense transformation, perhaps fairly called a revolution, in which institutions, culture, and science are changing or evolving rapidly. Emery and Trist (1973) predict that this process will continue for several decades. If so, Kuhn's dynamics of scientific paradigms may provide a useful context within which to seek to understand what is happening right now within fisheries science in Canada, and will presumably continue to develop for the foreseeable future.

With respect to limits on mobilization, a recognition and tentative acceptance of Kuhn's dynamics will lead to the inference that it is counter-productive to mobilize too broadly or organize too closely.

CONCLUDING COMMENTS

From the viewpoint of Kuhn's model and dynamics of science, the underlying assumption of the present paper is that intelligent, knowledgeable outgoing people working together co-operatively and democratically within an ordered process in which the rules are explicit and adjustable can resolve some of the problems facing us, to our subsequent long-term advantage. This is the assumption of the entire planning and decision process now building within the government. If this assumption is valid within the present time stanza, it is not clear how long it will remain valid. Presumably the life span of this (Kuhn's) paradigm can be shortened or lengthened by our activities within the process.

The above paragraph sounds trite to the point of embarrassment. But one of the preeminent rules in this process that we are learning is that assumptions, credos, paradigms, models, etc. be made explicit. Where this rule is not applied, the process fails to be rational.

It is, of course, inconceivable that all research and decision making will be forced into an explicit ordered sequence. As Emery (1973) points out, in any temporal Gestalt some problems are perceived as critical and some of these will be addressed in this way. The great mass of problems,perceived as being of minor significance, will be dealt with informally. Some of these will blossom into major problems even within the present Gestalt, or may come to be perceived as major with a change in phase of the culture and the formation of a new Gestalt.

This paper, partially or totally, may be trivial if all that it implies ultimately consists only of resorting and structuring of existing components of information, technical competence, insight, theory, disciplines, traditions, and personalities (see Dansereau, 1970). If so, then my endeavours would be analoguous to those of a child building a tower from a set of building blocks already arranged in the form of a church steeple. The toy tower is no more useful than was the toy steeple. A few scientists do play such games, apparently half consciously, using the work of many other scientists as blocks (or scientists as pawns) for their purposes. The decision-maker will of course seek to guard against supporting exercises that are analoguous to juvenile games. The serious practical objective is to build or rebuild structures and create processes - in science as elsewhere - that are useful in an appropriate broader context. It is questions such as these that the Science Council of Canada has been addressing in recent years (Lakoff, 1973).

In this paper I have attempted to see into the present, - to collect and collate pieces of insight and information on how one might approach the question of what should be the research strategy of Canada's Fisheries and Marine Service. Secondly, given that mobilization of researchers is occurring and will intensify, how might the mobilization occur to the long-term advantage of society, science and scientists.

Summary and Formulation of Some Strategic Questions

1. Science and scientists, and particularly fishery ecologists, are progressively being mobilized concerning natural resource exploitation and management, environmental disruptions, consequences of pollution on human health, etc.

2. The mobilization is occurring in a disjointed, ad hoc manner - essentially as a series of relatively unordered responses to a mix of crises including political, environmental, resource and poisoning components.

3. The conceptualization that appears to underlie the present mobilization appears to be thoroughly pragmatic:

a) How large should the research budget be and how should the budget be divided concerning resource management, eutrophication, toxic contaminants, assessments of major engineering works, etc.?

b) How much research should be done in the Arctic, Great Lakes, Gulf of St. Lawrence, etc.?

c) How rapidly can changes be instituted in the light of the likely gut reactions of strong personalities within the Service?

d) What existing long-term undertakings concerning support of scientific excellence or centres of excellence now constrain strategic options?

4. Without challenging the strategic importance of the above questions, this paper addresses the problem of research strategy from a more abstract viewpoint, though hopefully no less relevant than those above.

5. Following are some of the questions that relate directly to the conceptual framework sketched in the paper. The ordering is not intended to be in any priority ranking.

a) Given that "applied systems analysis" is the preferred format for a problem-solving approach, how rapidly and to what extent should it be stimulated to develop within the Service?

b) Should a formal screening mechanism be developed to identify different levels of problem complexity, only the more difficult to be approached formally as applied systems analyses ?

c) Perhaps as an aspect of screening, how can the important properties "scale and scope" be identified and clarified objectively?

d) Should the approach to multidisciplinary research and problem solving be formalized beyond the degree to which this occurs within applied systems analyses undertaken ad hoc on important issues?

e) How much support should be accorded to ongoing efforts to identify and clarify conceptual isomorphisms, among the disciplines of particular interest to the Service, in order to improve the efficiency of multidisciplinary work?

f) Should universities be encouraged to reorganize parts of their disciplinary framework, and should an environmental macro-discipline be explicitly encouraged to develop?

g) As the demands for particular kinds of technical, quantitative sophistication evolve, should a formal mechanism be developed to stimulate and direct the evolution?

h) In order to effect efficient links between technical quantitative competence and the various demands of different problems, can competence and problem characteristics be analyzed into mutually congruent sets?

i) Should the various traditions, within that science which is generally accepted to have some relevance, be assessed objectively for their possible future contributions, and supported in the light of such an analysis?

j) Should the structure and dynamics of interactions between a government agency, universities, advisory bodies, plus other non-governmental organizations be structured more explicitly in order that the general planning and decision-making process can become more efficient through division of labour upon which there is mutual agreement?

k) How can the transfer of science and technology be ordered between nations to be usefully effective yet not swamp a nation's scientific corps?

l) Would it be useful to classify an agency's scientists into three groups with somewhat different duties, related to the need for undirected research, mission-oriented research and program-dictated research?

m) How should the vertically-organized problem-solving scientific corps - including mission-oriented plus program-dictated researchers - be interfaced with the laterally-coordinated theory-seeking scientific corps - including undirected researchers plus many workers in universities?

n) Given that mobilization is occurring and will likely intensify, what safeguards will prevent excessive sacrifices of "truth and freedom".

o) By what criteria can a Service or institution know that proposed conceptual frameworks, mobilization schemes, perceptions of pending crises, etc. will be useful in practice for the "foreseeable future"?

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SECTION THREE

Formal Submissions
by
Participants

APPENDIX IX

NAS Panel for the Research Program of the International Institute for Applied Systems Analysis

"Ecological Systems"

Philip Johnson
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PANEL

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Mr. Richard Oliver

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Mr. Samuel McKee
Mr. Augustus Nasmith

OVERVIEW

The International Institute for Applied Systems Analysis has a unique opportunity to create a truly international intellectual community of scholars dedicated to the development and application of systems analysis to both theoretical and practical problems shared by peoples of many nations. We applaud this effort to carefully define and implement a research strategy that can benefit from this unique institution. These benefits will arise from the quality of the intellectaul effort and the unique opportunity to synthesize and catalyze methods of systems anlaysis for application to major societal problems.

Ecology will benefit world wide from the stimulus and insight to be provided by tools of the systems analyst. We wish to emphasize that both the discipline of ecology and the ecosystems context of most other problems to be considered by IIASA will benefit from ecological research undertaken by the Institute. Since IIASA cannot and should not overcommit its limited resources, projects of high leverage should be carefully selected. In many practical problems it may be sufficient to restrict systems analysis methods to problem definition, structuring of hypotheses and ordering of priorities. To the extent that emphasis is placed on methodology development, it will help in transfering such results to apply them to selected scenarios for alternative solutions of practical problems.

GENERAL RECOMMENDATIONS

Rec. 1 The NAS/US Advisory Panel on "Environmental Systems" supports the initial efforts of IIASA.

- The Project 7.4 on "Ecological Modeling and Control" is well conceived and organized. It is imperative that this initial project succeed for continued viability of the theme, and full support of the Institute is recommended.
- The issues raised by Symposium Leader Holling for the September 4-7 Conference on Ecological Systems[1/] constitute fundamental issues common to all ecological and environmental systems analyses. These need to be considered in future planning efforts and operations.
- Specific responses to issues raised above for procedures to (1) identify, (2) implement, and (3) document environmental systems efforts will be addressed specifically in presentations by U.S. participants Goodall and Mar at the September 4-6, 1973 IIASA symposium.[2/]

Rec. 2 The role of ecological studies within the Institute (IIASA) needs to be evaluated in the context of the central theme of ecology which prevails in other projects.

- Both Research Themes 6.5 (Urban and Regional Planning) and 6.7 (Environmental Systems) must rely heavily on ecological inputs. Besides Project 7.4 (Ecological Modeling and Control) the ecological contributions to the following projects need to be examined:

  7.1 Energy Systems
  7.3 Water Resources
  7.6 Global Simulation Studies

- Implicit in these recommendations is the recognition that the broader aspects of environemntal systems need to be considered in future contributions from the ecological community.

Rec. 3 Scientific emphasis and tactical leverage should be placed on the Institute's (IIASA) development of methodological capabilities in environmental and ecological systems analysis.

[1/] "Preliminary List of Issues for Consideration at IIASA Conference on Ecological Systems"

[2/] Goodall, David W., "Problems of Scale and Detail in Ecological Modelling"

Mar, Brian W., "Where Resources and Environmental Simulation Models are Going Wrong"

This is a rationale for the badly needed integration of ecology and systems analysis compatible with the unique abilities of IIASA organization and staff.

Rec. 4 The NAS considered several questions in addressing its recommendations and suggests that, among others, these questions be utilized by the Ecological Systems Conference in formulating future research strategies of the IIASA Environmental Themes.

- What are the unique contributions of IIASA to the scientific community?
- What are the problems that the IIASA's programs should address and, more critically, what are the criteria to be used in selecting research projects?
- How are priorities relative to problem assessment and policy implications established?
- How does the Institute relate to other researchers, decision-makers, and environmental programs?

Rec. 5 Specific attention needs to be devoted to identifying and interfacing with both the research community and the user communities so as to capitalize upon ongoing efforts and provide a unique coordination and synthesis of dispersed efforts.

Rec. 6 Provision needs to be established for continuity of projects and themes by incorporating into the research plan appropriate planning options and principles of staff responsibilities.

PROJECT CONSIDERATIONS

Ecological Systems

Recognition of the merits of Project 7.4 on Ecological Modeling and Control should not blind one to the need for exploring other fields in ecological modeling. Project 7.4, as illuminated by other documentation, is primarily concerned with delineation of zones of multidimensional space within which ecosystems are stable. In practice, one is concerned to know, not only whether an ecosystem will be stable within a certain zone, but where it will be within that zone, and for how long. In other words, one needs quantitative information about the state of the system, as well as the qualitative information as to whether or not it is within a zone of stability. A stable system may be useless for practical purposes; and careful cybernetic management may even enable an ecosystem to be maintained in a useful state within a zone of instability. The development of agriculture during the last six millenia may be an example.

The understanding of the carrying capability of ecological systems is fundamental to sustained management for many uses and combinations of different intensities of uses. In spite of wide application of this concept to grazing management, ecological modeling is so far largely inadequate to specify such usage loads for the other food, fiber, water, land, recreation or urban demands. Thus in addition to the items outlined in the Preliminary List of Issues, carrying capacity, indirect effects and quantitative prediction should be considered.

Insufficient attention has been given to the systems problem of interactions among components of ecosystems. It is imperative that data bases, functional relationships and systems techniques be developed which will permit dynamic coupling of the components and processes of ecosystems. This effort must be a prerequisite to assessing consequences of environmental impacts which are a result of systems component interacts, e.g., what is the response of system properties resulting from perturbations of its components?

A field of ecosystem modeling which has been little pursued, and which may be very important, is that of agricultural and silvicultural ecosystems. Application of the concepts of ecosystem dynamics, and their study by a systems approach, to the specialized ecosystems constituted by fields and plantations of crop plants might yield considerable dividends in the decades ahead in which food and fiber production has difficulty in keeping pace with population growth.

Human Interaction

A key element in ecological modeling and control, if they are to be of maximal usefulness in the real world, is human interaction. Man is at once the most adaptable of animals to ecological change and the major force in ecological change. Man's behavior, while complex, is not quixotic, and reasonable assumptions as to growth, distribution and consumption can be advanced.

Man's ability to adjust to change or his ability to bring about change is related not only to number and rate of growth, but to cultural level and political organization. The technologically advanced nations or peoples can determine major elements of the ecology of faraway places, and many of the exogenous elements that every model must admit are introduced by man -- the great destroyer but also the great creator. The world is being remade for man's use; a major problem of ecological modeling is to specify the long-term costs of careless or immediately beneficial actions.

In fact, when we speak of ecological control we really assume the ability to control man, to keep his modifications of the environment within sustainable limits and within such limits that the political divisions of mankind constitute a particularly bothersome problem since ecological changes initiated in one country have effects in others.

Economic concerns are of overwhelming importance since they determine the extension and development of agriculture and the exploitation of minerals and other resources. Furthermore, the use of a country's resources is not entirely of its own choosing. Worldwide forces of supply and demand are too powerful for even the largest countries to resist. And, not to be overlooked is the increasing economic and technological gap which separates the more developed from the least developed countries and which increasingly limits the areas of action left open for the less developed countries.

In short, Work Section II of Item 7.4 (Systems behavior in the <u>real</u> world) should be expanded beyond an "analysis of <u>examples</u> from ecology, economics, and cultural anthropology" to a thorough study of the implications of cultural, economic, and political developments. To do this will require the wide scale participation of social scientists, brought in from the beginning of the effort. In particular, demographers, resource economists, geographers, sociologists, and psychologists have much to offer.

Environmental Systems

The panel notes that environmental systems constitute one of the IIASA research themes, and that environmental problems are also involved in some of the other themes (notably 6.5) but that the only initial research project in this field is that on Ecological Modeling and Control. There are indeed environmental aspects of some of the other inital research projects -- Energy Systems (see the topics d and f on pp. 21 and 22 of the booklet), and Water Resources (see item 5 on p. 24) and proper consideration of these aspects demands that environmental advice be constantly sought in developing and implementing these projects. This could also be usefully done with some of the other projects in which environmental considerations are not mentioned notably those on Regional Planning, and on Global Simulation.

There is considerable risk, however, that in the absence of an advisory body on environmental modelling gaps in the Institute's coverage may never be filled. There are large areas within the Institute's terms of reference which are ignored, or barely touched on, by any of the proposed initial research projects. Just as examples, one may mention land use management, natural resource modelling, and meteorological and oceanographic applications of systems analysis.

There is a risk that the rather arbitrary list of initial research projects may prove self-perpetuating unless the Director is receiving regular advice from one or more panels with the responsibility of identifying new fields for Institute activity. It is proposed that one such panel should specifically be concerned with the environmental field.

RELATED INTERNATIONAL ACTIVITIES

A list with minimal commentary on some of the international activities already underway may help individual components of IIASA and its affiliates identify interfaces deserving attention. Individuals well informed on some of these may have obsolete facts or none at all about others. (The acronyms when used alone may serve to confuse communication, but are noted marginally below for reference.)

UNITED NATIONS

UNEP United Nations Environmental Program

(Maurice Strong, Palais des Nations, CH 1211 Geneva; also UNEP Secretariat, Nairobi, Kenya)

UNEMS United Nations Environmental Monitoring System

(UN Inter-Agency Working Group - meeting in Nairobi, January 1974) Existing national and international systems will be used, not only for data collection but for UN coordination -- especially for global and regional problems and for exchanging information on more local problems.

UNESCO/
MAB Man and Biosphere

(c/o M. Batisse, UNESCO, Place de Fontenoy, 75007 Paris) *Ad hoc* panels and continuing Working Groups under development. See: MAB Report series No. 2, "Expert panel on the role of systems analysis and modelling approaches in the program on Man and the Biosphere (MAB)."

INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS (ICSU)

SCOPE Scientific Committee on Problems of the Environment

(6 Carlton House Terrace, London SW 1Y 5AG) has elements of the flexibility of non-governmental organizations. Its Second Assembly meets in Kiel (F.R.G.), October 4-11, 1973. Numerous sub-organizations, many meeting infrequently, have specialized interests which can be clarified through SCOPE if desired. (SCOPE has identified ICSU family interests related to the Stockholm Conference recommendations.) Only a few need current comment here:

SCOPE Commission on Environmental Monitoring and Assessment

(The role on monitoring is advisory, following a responsibility in the document SCOPE 1; "assessment" is construed as an analytical and synthetic function, leading to "evaluation" of intellectual and practical problems and advice on a flexible basis.) Meetings September 17-21, 1973 at London should provide input to SCOPE's meetings at Kiel.

SCOPE Commission on Simulation Modeling

May 1973 documentation relates particular functions, already formulated mathematically, to a variety of problems likely to be amenable to treatment in the future.

SCIBP Special Committee for the International Biological Program

has work entering phases of synthesis in 1972-74 (continuing longer in some cases under unknown international auspices). Working groups particularly active now on ecosystem analysis cover:

Woodlands (D. E. Reichle, Oak Ridge National Laboratory,
Oak Ridge, Tennessee 37830, USA)

Grasslands (R. T. Coupland, University of Saskatchewan,
Saskatchewan, Sask., Canada)

Tundra (c/o T. Rosswall, Wenner-Gren Center, Sveavägen
166 8tr., S-113 46 Stockholm, Sweden)

Arid Lands (Ray Perry, CSIRO Rangeland Research Unit,
Canberra City, A.C.T. or in USA, David Goodall,
Utah State University, Logan, Utah 84322)

Wetlands (Jan Kvet, CSc, Institute of Botany, Cz. Academy
of Sciences, Stará 18, Brno, Czechoslovakia)

Upwelling (Richard Dugdale, Department of Oceanography,
University of Washington, Seattle, Washington
98195)

Human Adaptability (Paul Baker, Department of Anthropology,
Pennsylvania State University, University Park,
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APPENDIX X

Some Thoughts on and Proposals for the "Ecological System" Research Project

Hans Mottek
(GDR)

Introduction

The starting point for IIASA research should be not to analyse individual ecological systems, but to begin with their interconnections, their integration in the whole system of the physical environment. Through system analysis it should be attempted to achieve optimum "management" of the physical environment with special consideration for environmental protection for man[+)] and his resources plus the rational use of the natural resources. Such a task should be set, not only because of the generally acknowledged urgency of the problem, but also because the application of system analysis on the management of the physical environment in one country or globally has not yet been exhaustively examined. There would hardly be any over-lapping with already existing international themes being dealt with by the UNO and UNESCO. On the other hand, the findings of such themes set by the International Institute for Applied System Analysis (IIASA) - such as water systems, energy systems, town systems, public health system and also the optimisation of dynamic systems, organisation of management systems, etc. - could find application. All these subjects are obviously related to the questions of optimal management of the physical environment.

1. Basic concepts

The effects of social activities on the natural environment, particularly production and its end product, consumption, have increased tremendously in recent decades. This makes it necessary to look at the totality of these effects on

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+) including the social problems

the large natural spheres, particularly the biosphere and also on the humanly created technosphere, in a complex manner, i. e. taking into account all essential causes plus their side and delay effects above all on the balance of the existing ecological systems. In addition there exists clarity that the retro-action of changed nature and the built (technical) environmental ecosystems on the present and future needs of man and their satisfaction must be examined in detail. The relationship of society and environment should be seen as a cybernetic system with complicated inter-connections. Thereby, the immediate and retarded effects of pollution and the exhaustion of natural resources which do not regenerate themselves are brought into the foreground.

Out of all these considerations, it has proved necessary to guide social environmental activities in such a way that the environment is influenced to an optimum. This demands an effective "environmental "management".

2. On environmental 'management"

2.1 Goal function of environmental management"

The basic problem to be solved for environmental management, as for every other, is to specify operable goal functions plus the necessary restrictions. Our considerations on this are directed towards: protection of man and his (natural) resources. In the socialist countries there exist deliberations to solve this problem in respect of production as the most important factor of social activity affecting the environment in the following way: To include protection of the environment, not only in the form of restrictions, to be built in the optimization function of national income, but to raise the environmental qualities to a goal of equal social importance. However, it would be possible to include the loss of environmental qualities into the term "national income". One reason is that positive aims are always more effective than restrictions, which, however, one cannot do without (completely).

The second question being examined in the socialist countries is in how far one can put into effekt, that on the quality of environment is a goal, also for decisions of the subordinate activity units. In capitalist countries, it would hardly be possible to achieve this, because of the conflicting goal of maximum profits. However, decisions based on aims for maximum profit certainly do not guarantee protection of the natural, physical environment and of man.

Starting with the goal functions, optimum decisions must be made which modify the form, quality, proportion and locality of operation on environment, in other words: optimum decisions must lead to the employment of environmentally oriented technologies in the right quantities, proportions and in the right distribution.

2.2 Cognitive system

Optimal decisions in the above sense are currently inhibited, not only by a lack of environmentally oriented operable goal functions, also valid for society. An inhibiting factor too is the insufficient knowledge of the effects of various interference groups on the various systems of the natural environment on a short, medium and long-term basis, and also the localities. In addition, they are also inhibited by insufficient knowledge of the effects, e. g. of pollution on human health, on the satisfaction of elementary human needs, again taking into account the locality and time horizon.

In consequence of this insufficient knowledge, when assessing a decision, one is confronted on the one hand with a clear, definite usefulness in the near future, on the other with uncertain, unclear damage in the distant future. In the same way, a lack of damage is less noticed than the immediate expenses necessary to prevent damage. This often leads to an under-estimation of the dangers, and on the other hand to certain security reserves being built in - to avoid catastrophe - which would not be necessary if one had sufficient knowledge of the exact dangers. Reduction of such uncertainty about the consequences of environmentally relevant activities would then also bring concrete economic benefits which could be measured even in current criteria of evaluation, i. e. money.

Naturally, environmentally relevant decisions, like all decisions affecting the future, cannot be made with complete certainty. This demands the construction of an effective, cognitive sub-system in which environmental research must play an important role. It is urgently necessary to rapidly increase such research.and gain exact theoretical knowledge and data on

a) changes by man in the system of the physical environment and their inter-relationship,

b) the changes in human needs and their satisfaction in the present and future as a consequence of changed conditions in the physical environment,

c) possibilities of changing technical factors and their structure in a direction that is positive for the environment.

Based on the knowledge to be gained in a) to c) or already existing, there should be built up a continuous, concrete observation net-work of the environment.

2.3 Forms of control for environmentally relevant activities

2.3.1 Legislature

Experience has shown that attempts to put optimal decisions on protection of the environment and man and on the efficient use of the natural resources, into practice are often met with many difficulties which must be analysed and taken into account when constructing an environmental 'management' system.

Up to now, the main instrument has been the legislation. However, this has always been applied as restriction of the goal function, i. e. as a prohibition. If the quality of the natural environment is to be the immediate goal function, in the socialist countries, the planning of the economy can become the decisive factor for improving the natural environment, although prohibiting laws cannot be dropped altogether even then. If one accepts the proposed extension of the term "national income", then one must look upon improvements to the environment - e. g. avoiding pollution of the air and water, equally as much as positive production, etc. - as one does at the making of traditional goods; thus pollution caused by factories should be considered and treated as negative production.

2.3.2 Administration

The second important instrument is the administration. For this sphere such questions should be examined as the organisation of independent inspections for environmental protection, and also the problem of financing environmental management.

2.3.3 Educational and other measures to influence attitudes

The laws, the planning of the economy and the administration cannot lead to optimal environmental management, if they are not supplemented by educational endeavours. Corresponding moral forces - particularly for putting decisions into effect which are to avoid pollution for the more distant future - must be developed and placed in the service of the environmental management.

3. Research themes

3.1
The essential research themes can be seen from 1. and 2. (One must differentiate between themes for general environmental research and for IIASA.) General environmental research - apart from the questions of environmental 'management' - are described under 2.2.a) - c): i.e. the change in environment

systems, their retroaction on human beings and the development of environmentally oriented technology. Their examination would help to decrease the uncertainty of environmentally relevant decisions and serve to build an effective environmental 'management'.

In the Institute itself, the complex themes under 3.2, 3.3, 3.4 and 3.5 should be placed in the foreground.

3.2

The inter-relationship between the various sub-systems of the physical environment. This is important because the optimisation of a sub-system and even of all sub-systems is not yet the optimisation of the total natural system.

The dynamics of development within each of the systems in the natural environment - especially that of the biosphere - and also their inter-connections should be investigated. If this is agreed on, one could directly apply the findings of research on the optimisation of dynamic systems which would also have to be gained in the Institute. During the course of this, a comprehensive model of the physical world and its inter-actions with society would come into being. Thus a Prognosis (I) for the further development of the physical world could be created, on the condition that there are no radical changes of influence on the environment in its tendencies of character, size and structure.

3.3

The problems named under 2.2c) should be investigated in the Institute, i. e. the natural-scientific and technical possibilities of an environmentally oriented technology; in particular the prerequisites and possibilities for recycling, increasing resource productivity, discovering new resources, in other words: the natural-scientific and technical prerequisites for growth in harmony with environment. On this basis, Prognosis II could be elaborated, which investigates the development of the physical environment under the pre-condition that the influences on the environment will be decisively changed within the framework of the possibilities discovered.

3.4

System analysis of existing goals for current environmental management, its contradictions, in particular contradictions between the sub-system of environmental management and its total system.

System analysis of the decision system - particularly of the cognitive system. In the foreground here, is the question of decisions under uncertainty, plus the so-called risk evaluation.

Analysis of the carrying through systems - particularly concrete examination of how environment protection laws have been put into practice up to now and the conclusion to be drawn.

3.5

Cognitive demands within the framework of the decision system of environmental management make it recommendable to formulate research proposals to the international scientific institutions and to world science - in other words, beyond the framework of the Institute.

A task for Institute research would also be elaboration of a proposal for comprehensive, scientifically substantiated, international environmental research program.

Scientific substantiation means that the risks connected with existing uncertainty are more exactly evaluated and therefore, of course, also the degree of uncertainty itself. Certain research priorities would result from this evaluation which the Institute could propose to the competent international and national organisations.

3.6
Elaboration of such a program, based on the analysis of the international level of knowledge or ignorance about essential questions of environment and its management, with special consideration for the level of knowledge on decisions made under uncertainty and risk evaluation in environmental questions, should comprise the first stage of IIASA investigation into this theme. Research groups of the countries participating should present their projects, which would then have to be co-ordinated centrally. On this basis, the IIASA's own research program could be made more concrete. Those research projects still remaining could then run parallel.

4. The questions of optimal influence of the natural environment by society, had been considered in this paper on the basis of management by individual states.
   However, the growing necessity for an international organisation has become increasingly obvious. This should be founded and those already existing should be involved in the global environmental management.

G. Schmidt-Renner and W. Mende GDR

Annex
16.8.1973

Notes on the diagram "Society-Environment Relationship and its Management"

Notes to Folio I [+)]

(1) The basis for all understanding and modelling of the relationship between society and environment is the continual necessity to reproduce society. It is objectively stimulated by need pressures of society and it is put into effekt as need satisfaction. It is subject to the urge for extension (development qualitative-quantitative); it behaves adaptively (27).

The reproduction of society can be considered from the viewpoint of purposes, means, forces and achievements whereby one must differentiate methods of reproduction change over long periods of time and also differentiate in various parts of the earth.

(2) Reproduction serves (always and everywhere) to maintain and develop (as extended reproduction) the biotic and social (double) existence of society, in other words to maintain and develop its material and social structures, etc.

(3) However, the basic purpose of reproduction is the safeguarding and extension of the biotic (physical) existence of mankind through food, clothing, housing, etc. These (elementary) need complexes have objective priority before others. Their satisfaction is the prerequisite for intellectual activity.

[+)] Numbers in the text co-incide with numbers in the diagram (Fol. I)

(4) While biotic reproduction is started by the individual's urge for self-preservation, it is controlled by the social fields of life, by the social (socio-economic) laws controlling him, and also by special institutions (e. g. distribution).

(5) Biotic reproduction takes place through production of commodities and services, and through their consumption. An inter-action exists between both basic reproduction operations: the need for consumption stimulates production; production is perfected through consumption; production stimulates consumption.

(6) The place for reproduction of society is necessarily the earth. It is the global reproduction milieu and thus comparable to a huge space ship to which society is bound nolens volens. Society reproduces itself in and through its reproduction milieu (nature). The earth supplies the elementary reproduction agents such as: place of reproduction, water, biomass and other (abiotic) matter (e.g. minerals), energy.

The natural resources appear in many substantial forms; they differ in various parts of the earth (e.g. Arctis - tropics) and in time (stone age - "atomic age").

Air, water, soil and areas of land are the main media of biotic (natural) existence (and development) of society through reproduction. The properties and functions of the structures of these main forms are decisive for global reproduction of the society.

(7) The reproduction of the biotic, natural existence of society takes place in the sphere of nature.

(8) The more society interferes with the natural household of matter and energy and the exchanging processes between these with the help of technical means, the more the sphere of biotic and abiotic (natural) matter, energy

and processes are transformed into a technosphere. These changes are irreversible; there can be no "back to nature", but it is possible to maintain natural potentials and processes by rational regulation of the sphere of nature.

This means that the material output of the technosphere must also become its input, in other words, the technosphere must not only respect the basic laws of the circulation of matter in the natural sphere, but also emulate them. This demands further that resources be used economically and resource productivity be increased.

(9) - (10)

Growth is a general characteristic of evolving systems. The reproduction of a society growing in numbers and its special structures (through production and consumption) is also increased in quantity and quality. During the course of time this happened - without taking the effects on the natural sphere into account - more quickly (super-exponential) but unevenly in various parts of the earth, and for a long time until now in favour of certain areas (e.g. USA) to the disadvantage of others.

The regionally uneven development of social reproduction is the inevitable result of the differing socio-economic factors at work in the various regions, which also cause further differences e.g. between classes and strata.

(11) - (12)

The inevitable consequence of growing reproduction is the growing consumption of natural matter and energy, is a growing amount of waste and reshaping natural areas (through housing, roads, factories, etc.)

Such huge, combined and overlapping processes of reproduction - without respect on the natural sphere - leads to wearing down and pollution (regional) at a faster rate than nature is able to regenerate and clean itself.

Negative quality jumps occur through summation (accumulation) of the negative effects of social activity in the natural sphere (differing in time and place).

The causes for this phenomena are differently determined socio-economically, as are also the reflections within society on this phenomena and their causes.

(13) Objectively, critical conditions for reproduction occur in parts of the earth which can be defined; more are expected in future; worried prognoses appear for other parts and finally for the whole globe. It is now necessary to prevent the negative expectations for the future coming true.

(14) Inside the society, with increasing population, increasing need pressure, demands made and developing reproduction, etc. grow excitation levels of noise and other stressors; they go beyond the human ability to adapt.

(15) The growing wearing down and pollution of natural reproduction conditions on the one hand (11) - (12) and the increasing overstrain of human ability to adapt on the other (14) lead to inhibitions in the reproduction of society. The conditions of reproduction become worse, the reproductive system more strenuous; more must be expended in natural resources and human energies for the same reproductive effect, if we have in mind the same level of productivity.

Through deterioration of the qualities in the natural sphere for biotic reproduction and through the increasing level of excitation, public health and welfare also deteriorates; the population - despite a higher average longevity - tends more and more to have so-called diseases of civilization. Whole social structures deteriorate (slums, ghettos); crime; conflicts and emergency conditions grow.

(16) All this and more penetrates the consciousness of the population via the sensoric system, and through signals given by the communication system, is made known to the "managements", as those responsible bodies of state and society will be called from here on.

(17) The "managements" (also scientific!) gain greater insight into the critical conditions and expectations for accumulation of critical processes arise (13). Conceptions for counter-actions by society are elaborated. These vary in line with the situation, the amount of insight and social responsibility of the "managements", and also have differing social purposes.

The conceptions on counter-actions - i.e. on actions by society or its executive bodies, etc. against the negative effects of social reproduction acts in the natural sphere - as well as the counteractions themselves - are gained (put in a somewhat simplified manner) through

(18) cognitive actions described in block (18), to which one must add sensoric observations, their intellectual processing up to decisionsmaking plus propaganda and education. They are carrying through

(19) a put into effect system composed of

(20) legislatives,

(21) administrations and

(22) executive actions of definite institutions and create a

(23) field of result in the natural sphere to the advantage of social reproduction.

(24) A control system first in the administrative field (21) will state in the executive field (22) and in the field of the results of counter-actions and back-feed them to

the three previous fields (18) - (21) of the put into effect system (administrative, legislative, cognitive). Their co-operation (18) - (21), and at the least the increased insight inside cognitive system on the critical events and expectations, their causes and effects, will inevitably lead to demands for

(25) qualification of social counter-actions against the negative effects of social reproduction actions in the natural sphere of reproduction.

This block (25) should correspond about to the present level of insight on our globe, at least in the industrialised nations. One must also take into consideration that the counter-actions will differ as to time and place, and also in importance, intensity, effort and success.
From all (available) publications on the subject, it is obvious that a phase of qualified and also globally co-ordinated counter-actions are already beginning. They can be expressed as

(26) qualified environmental research and formation (management) which can be understood as the feed-back from the (controlled) results of earlier counter-actions (17). However, they should now lead, not just to simple prohibitions, but

(27) in the course of time, to a successive retro-action on the whole method of social reproduction in the natural sphere (1) and (6), which leads to a completely new attitude of people or the "managements" to the elementary conditions of reproduction and to an environmentel oriented technology and resource "management".

For this, enlightenment through public relations work with the people, but also with the "managements" (see block 18) will have to play a significant role.

In the following (Fol. II), the main characteristics and trends of counter-actions in the cognitive field are to be described.

Notes on Folio II

(1) Main task: Optimal environment 'management'
The environment of the reproduction system is continually developing. However, it is necessary to consciously control this development and use it to an optimum in order not to disturb the prerequisites of reproduction through side and delay effects: reproduction of the environment is to be understood not only substantially (only such matter is taken from the environment as is returned to it), but also functionally. The changes to the ecosystem, which are necessary for extended reproduction, must have a long-term stability and make possible an evolution in unlimited time horizon. This means, the blind evolutionary mechanismus must be consciously taken over into the responsibility of society. The task is, not only to avoid crises within the systems (by prohibitions), but also to set and realise positive aims for the evolution of the whole environment; this means optimal influence of the environment through the conscious guidance of human activity, in particular, reproduction of society.

This demands far more complex goal functions than before; this is the only way to prevent or decrease a negative influence on the environment.

(2) General principles
These should determine the direction taken by the environmental management system and should be taken into account during every detailed investigation.

(3) Globality of environmental problems and 'management'
All examinations of and decisions on the physical environment (both as regards spacial and functional extension) should a priori be related to the global aspect of the problem.

Decisions are often made for a practicable solution to one sector, but they turn out to be negative for the whole. Therefore, it is necessary to see the ecosystem in its totality which often puts a completely different light on the decisions to be taken for the sub-systems.

Global values make up essential reference measures and co-ordinates for the adjustment and timing of sub-systems. An optimal decision cannot be gained alone through transition to more comprehensive sub-systems, so one presuming the more comprehensive a system is, the nearer one is to a correct decision. However, it is characteristic for the problem of environmental 'management' that the decision for the transition from a very large to a global system can turn out completely differently. Thus, it is necessary to create a global model of the physical environment (ecosphere) by which one can orient decisions on details.

(4) Complexity of environmental problems and 'management'
The ecosystems are generally very complex. The elements and sub-systems vary greatly (in contrast to the particles systems in physics) and they are coupled together in a highly complicated manner. Only seldom can sub-systems be isolated in such a way that only few couplings to the rest system need be considered. Equally simple cause-effect thinking is insufficient. Complicated retro-actions and time-lags (both spacial and functional) can occur far away from the causes. Particularly, the so-called counter-intuitive behaviour can appear whereby systems not only resist outside pressure, but even gain stability under such pressure, if this does not go beyond a certain intensity.

There exist strong spacial inhomogenities (e.g. density zones), time differences and fluctuations, which are of vital importance: catastrophes are noticeable first locally and cause suitable measures being taken to prevent a

catastrophe for the whole system.
There also exist priority decomposing sectors of the reproductive system, so that sectorisation and regionalisation of a global ecosystem model is necessary. However, globality and complexity by no means entails uniformity of approach, on the contrary, stronger spacial and sectoral differentiation is an essential feature of these systems.

(5) Systems approach to environmental problems and 'management'
Systems approach is a self-evident requirement for investigation of ecosystems. One must consider the ecosystem and the society as a whole. But what is meant by whole system? As is customary for ecosystems, a system coupled with an environmental domain or a function continues

to exercise influence far into its surroundings. Therefore, the system borderlines are flowing and depend on the degree of precision of the examination and on the individual function being investigated. E.g. all substances and mechanisms of a geophysical, biotic and technical nature participate in the environmental system atmosphere which feed or remove any matter or form of energy into and from the atmosphere.

The system borders are largely pragmatically determined, i.e. the addition of further cause complexes does not essentially alter the examined behaviour.

As the ecosystems are large and complicated and are open thermodynamic from a physical viewpoint, properties characteristic for these systems occur repeatedly and must be taken into account when applying interference; e.g. time-lags, complicated time response, reaction at far distant sub-systems, counter-intuitive behaviour, releaser effects, tilting effects, stability zones with complicated and in some cases sharp transitions to instability, rebound effects, highly sensitive points, adaptive band-widths, operative-widths, side and delay effects, hidden effects (despite the same output, the function or structure changes), overshoot of reaction, etc. Such properties lead eventually to the side and delay effects dominating over the desired ones, and are of special significance for the systems approach to an optimal environmental'management.

(6) Evolution of the ecosystem

The whole environment is continually developing. It is included into the geo-physical, the biological and also into the cultural and technical evolution.

So long as the energy feed from the technical sector was very small, human influence on the evolution of the reproductive system's environment (mainly the natural environment) was also very small.

Now human society undertakes to determine the direction of further development, both by releasing large amounts of energy and transforming matter, and also through interference at exceptionally sensitive points of the ecosystem where very big effects can be caused by only small interference (e.g. changes in climate through condensation germs, ammonium, etc.). This also retroacts on the evolution of the social system.

Human society is a self-stabilising, evolving system which can maintain its own structure only with the help of a high metabolism in matter and energy with the environment. These metabolic flows necessarily generate an entropic degradation of the environment, but, because of the continuing flow far into the surroundings, they also cause a positive and / or negative evolution of this environment. The disturbances of the system from this environment become more and more complicated and compels society to refine its stabilisation mechanisms. This, in turn, creates higher entropy production and higher flows, which again causes further increase in the disturbance potential of the environment. In this way, the system is continually forced to refine its own structure and, if the outer conditions allow, to grow. Evolution of such a system without simultaneous evolution of its environment is impossible. So, conservation of physical environment in the strict sense is, therefore, also impossible. The important problem is, to harmonise the technical and social evolution with the natural evolution in such a way that the natural mechanisms maintain their rightful place also in a world endowed with the strongly purposive mechanisms of society. As continual development in the environment cannot be avoided by technical means - on the contrary, the more technique used, the more changes come about - one must see to it that the metabolites (waste and disturbances) are pushed away as far as possible and that these changes occur in such a manner that they are acceptable and desirable for human beings. The problem is the search for a growth path in harmony with environment.

(7) Long-term stability of the ecosystem

The assessment of measures depends on the time horizon. E.g. for a short time one can maintain rapid growth by plundering the resources, but after some time this will lead to a collapse of the productive system. One essential condition to achieve a desirable direction of evolution in the environmental system is that the evolution should not lead in a finite foreseeable future to instability or catastrophe; for a parameter which goes out of a favourable intervall (e.g. temperature) causes by possible tilting effects deterioration of the total structure of the system. Thus, one must choose paths of development for the evolution of human society and its environment, which run towards an unlimited time horizon without instabilities or catastrophes.

(8) Decision under uncertainty

All necessary decisions on management of the environmental systems are taken under pressure of time and with incomplete information; they are necessarily provided with a risk that must be assessed and, possibly, quantified (risk evaluation). It is possible that an apparently positive operation (such as within the framework of global technology) cannot be taken because the risk is too great. With thorough assessment, alternatives often receive a completely different priority, as also when one evaluates the effects of missing information. Risks and decisions also depend on recognised side and delay effects as well as hidden effects.

(9) Environmental protection and formation
Because of the high degree in the growth rate of pollution and wearing down of the environment, priority should be given to preventing further immission of wastes and noxes (such as through inserting filters, etc.) over projects on environmental formation and environment oriented technologies, because the latter would need very long time to become widespread and effective.

A general reason exists for the maintenance of the natural ecosystems: So long as the complicated structure of these systems is unknown, it is better strategy to maintain the highly vulnerable balanced systems or regenerate them back to an undisturbed condition.

The biological evolution is the product of a self-stabilising system several billion years in action which one must learn to understand.

(10) Environmental research as part of environmental 'management'
Research is the prerequisite for achieving desired effects and avoiding undesired effects on the environment. On the other hand, experience will show gaps in the management's knowledge, so that a close inter-action exists between management and research.

(11) Pressure of time and down-to-earth practice
Characteristic for environmental management is the short period of time between a critical situation becoming obvious and it actually occurring. During this period counter-actions may have to be taken and come into effect with considerable time delay. This pressure of time demands down-to-earth research.

(12) Socio-economic determination and differences in environmental measures operations

Main cause of the problem is the social use of natural resources for social reproduction. This results in wearing down (consumption and use), and pollution through wastes. Varying socio-economic systems pursue basically different methods: on the one hand, satisfaction of needs (reproduction) via the mechanism of maximum profit for owners of capital, and on the other, direct satisfaction of needs through a non-profit system of commodity and money. Profit optimisation causes a different, rigorous attitude of the economy towards natural conditions (profitable exploitation of the ecosphere). The large social systems now existing - despite some points of formal agreement on environmental problems - have different starting points, different purposes and different possibilities of solving the problems.

(13) Differences between industrialised countries and developing countries

The economic conditions of the developing countries often forces them to use their natural resources to excess. In addition, they have not the money to finance protective measures. In some of these countries it appears that within a short time they will achieve the same level of production as the developed industrial nations, but without the same resource productivity. Therefore, it would appear sensible for the developed industrial nations to help the developing to use their non-regeneratable resources in the most efficient manner. The danger exists that the latter will repeat the errors of the former by plundering their own resources, instead of taking more positive paths of development.

(14) General tasks of environmental management

In the following points, world-wide tasks will be proposed for an organic environmental management. They would need to be carried by many world-wide environmental institutions in cooperation.

(15) World-wide co-ordination of counter-actions

Co-ordination is necessary because, e.g. improvements in one country often lead to environmental deterioration in another (building of dams, etc.) or improvements in air and climate are impossible on a national scale.

(16) World-wide strategy for global maintainance and cultivation of large environmental sectors and resources (climate, oceans, energy, water)

Each of the environmental sectors require specific maintenance and cultivation which are only possible through co-ordinated international activity. Sooner or later, the preventive measures to limit emission of noxes must turn into active cultivation and cleansing with world-wide participation.

(17) World-wide practicable tactics for ubiquitous environmental operations

Certain ecosystems are spread throughout the world, so some effects and retro-actions plus accumulative processes and distribution mechanisms can be seen everywhere (waste deposits, water reservoirs, oil processing techniques). Standard methods and technologies should be worked out for these cases: standard module techniques for practical environmental protection and operations, environment engineering.

(18) Information system and data bank for environmental information

The very dispersed findings on environmental research and management - resulting from work in many fields - should be compiled into one information system, and made available in accordance with the UNISIST recommendations.

(19) International system for observation and collection of data

Should supply the data necessary to set up an environmental status and control of noxious emissions.

(20) International norming and standardisation

This can be set up in a similar manner to norm systems already existing in the technical field. Definition of terms, basic categories, specifications, measured quantities, measuring methods, compatibility of measurement theories and adjustment methods are urgently required.

(21) International system of checking counter-actions

Controls the world-wide and supra-regional counter-actions of environmental management and informs the corresponding executive and research institutions.

(22) Analyses of how national environmental protection systems work

The analysis and comparison of various national systems of environmental protection is a source of experience for a world-wide net-work of environmental management. It also provides the possibility of testing environment oriented measures under differing socio-economic conditions. In addition, the efficiency of these systems can be raised to a national, regional and local level.

For the socialist countries, one could consider exchanging experiences on how best to include into the economic plans protection of the environment and attempts to raise its quality.

(24) Construction of a model of physical environment and its relations to society (ecosphere model)

An urgent task for research is to construct a model describing all formalisable and parameterisable properties of the most comprehensive ecosystem (ecosphere) and their inter-dependence and their interactions with society, that means the effects of a decisively 'new attitude' to environment including all its social aspects. One can integrate into this model those already developed of ecological part-systems and those to be created within the framework of IIASA of energy systems, water systems, etc. In addition, it would be necessary to elaborate a resource management model, a model for the influence of global human technology on the climate, a model for the effects of environmental oriented technologies and a model describing production, transformation and absorption of the various types of pollution and other functional and structural disturbances of the ecosystem.

The integration of these part-systems into a whole, needs differentiation in accordance with sectors, regions and ecomechanisms. It would then represent a huge dynamic system which could better simulate the inter-relationship of various ecosystems step by step, and thus make it possible to gradually recognise the chronological development of the whole ecosphere, the rise of instabilities and disharmonies.

Within this model, planned operations in the environment and its effects and the influence of "new attitudes" and environmental oriented technology should be simulated and assessed through many alternatives. On the basis of such a model, stepwise more reliable prognoses could be given about the evolution of our global ecosystem.

The other points will not need explanation here.

FOLIO I

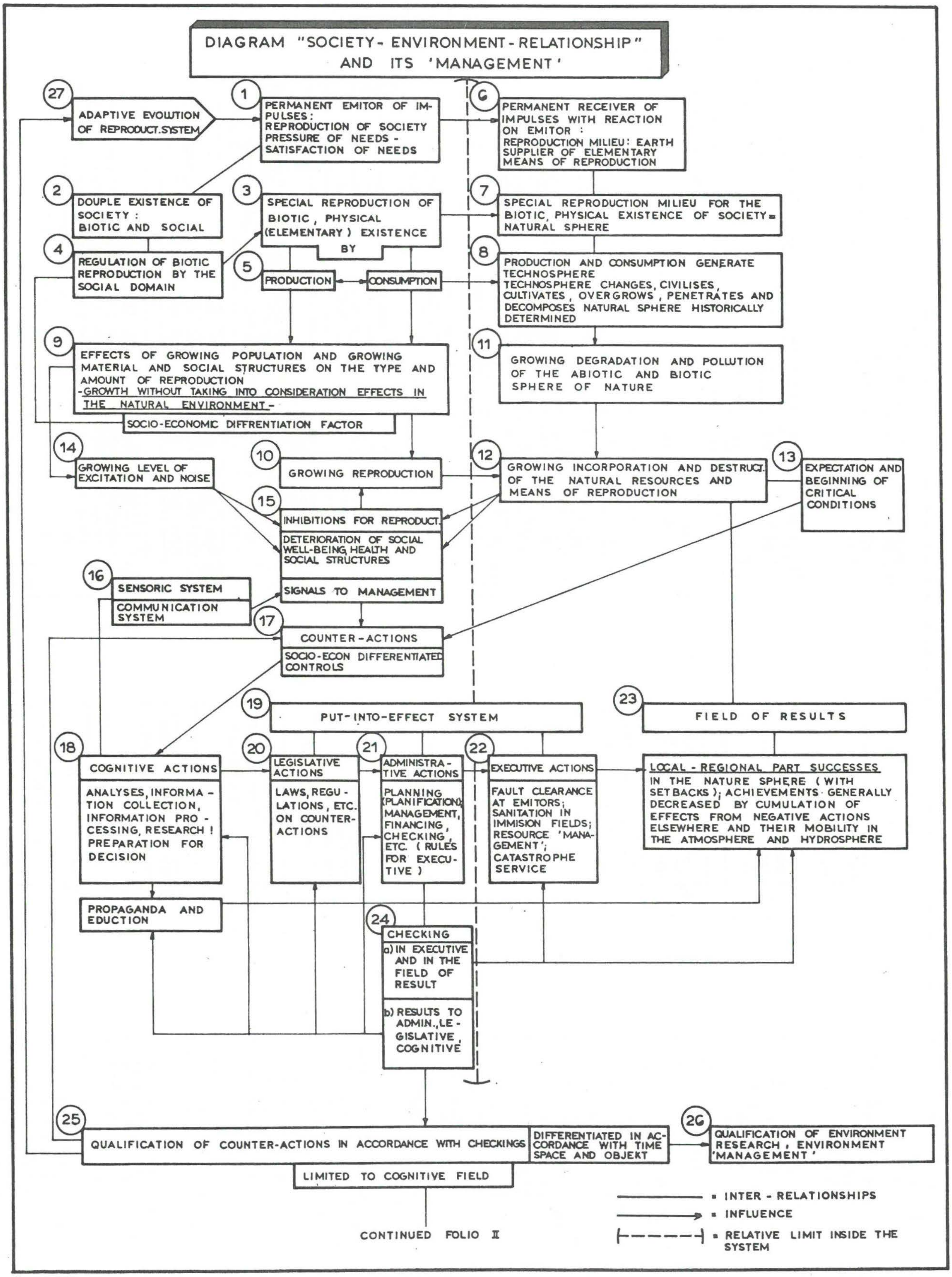
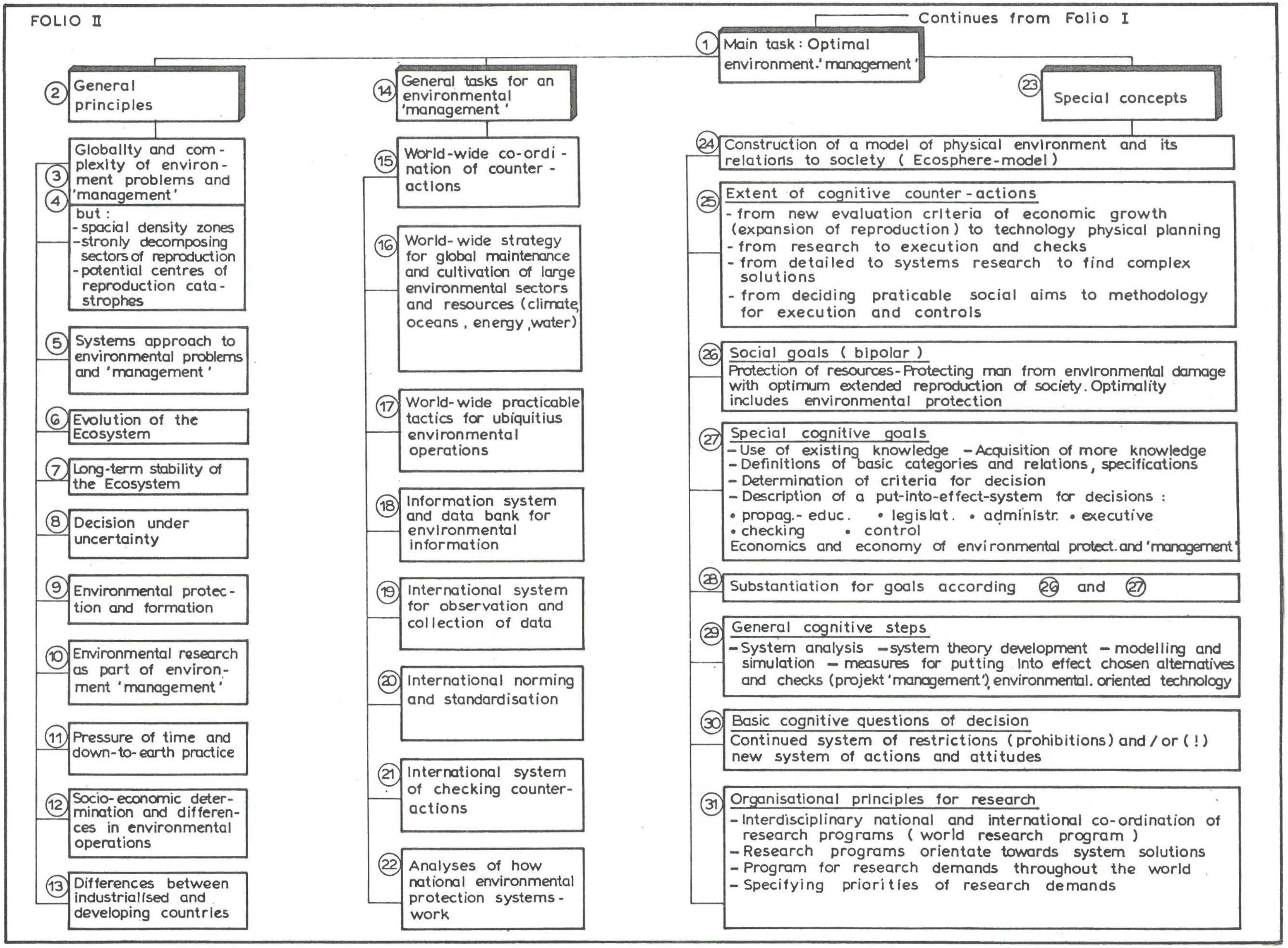


DIAGRAM "SOCIETY - ENVIRONMENT - RELATIONSHIP" AND ITS 'MANAGEMENT'
27
ADAPTIVE EVOLUTION OF REPRODUCT. SYSTEM
1
PERMANENT EMITOR OF IMPULSES: REPRODUCTION OF SOCIETY PRESSURE OF NEEDS - SATISFACTION OF NEEDS
6
PERMANENT RECEIVER OF IMPULSES WITH REACTION ON EMITOR: REPRODUCTION MILIEU: EARTH SUPPLIER OF ELEMENTARY MEANS OF REPRODUCTION
2
DOUPLE EXISTENCE OF SOCIETY: BIOTIC AND SOCIAL
3
SPECIAL REPRODUCTION OF BIOTIC, PHYSICAL (ELEMENTARY) EXISTENCE BY
7
SPECIAL REPRODUCTION MILIEU FOR THE BIOTIC, PHYSICAL EXISTENCE OF SOCIETY = NATURAL SPHERE
4
REGULATION OF BIOTIC REPRODUCTION BY THE SOCIAL DOMAIN
5
PRODUCTION
CONSUMPTION
8
PRODUCTION AND CONSUMPTION GENERATE TECHNOSPHERE TECHNOSPHERE CHANGES, CIVILISES, CULTIVATES, OVERGROWS, PENETRATES AND DECOMPOSES NATURAL SPHERE HISTORICALLY DETERMINED
9
EFFECTS OF GROWING POPULATION AND GROWING MATERIAL AND SOCIAL STRUCTURES ON THE TYPE AND AMOUNT OF REPRODUCTION -GROWTH WITHOUT TAKING INTO CONSIDERATION EFFECTS IN THE NATURAL ENVIRONMENT-
SOCIO-ECONOMIC DIFFRENTIATION FACTOR
11
GROWING DEGRADATION AND POLLUTION OF THE ABIOTIC AND BIOTIC SPHERE OF NATURE
14
GROWING LEVEL OF EXCITATION AND NOISE
10
GROWING REPRODUCTION
12
GROWING INCORPORATION AND DESTRUCT. OF THE NATURAL RESOURCES AND MEANS OF REPRODUCTION
13
EXPECTATION AND BEGINNING OF CRITICAL CONDITIONS
15
INHIBITIONS FOR REPRODUCT.
DETERIORATION OF SOCIAL WELL-BEING, HEALTH AND SOCIAL STRUCTURES
SIGNALS TO MANAGEMENT
16
SENSORIC SYSTEM
COMMUNICATION SYSTEM
17
COUNTER - ACTIONS
SOCIO-ECON DIFFERENTIATED CONTROLS
19
PUT-INTO-EFFECT SYSTEM
23
FIELD OF RESULTS
18
COGNITIVE ACTIONS
ANALYSES, INFORMATION COLLECTION, INFORMATION PROCESSING, RESEARCH ! PREPARATION FOR DECISION
20
LEGISLATIVE ACTIONS
LAWS, REGULATIONS, ETC. ON COUNTER-ACTIONS
21
ADMINISTRATIVE ACTIONS
PLANNING (PLANIFICATION), MANAGEMENT, FINANCING, CHECKING, ETC. (RULES FOR EXECUTIVE)
22
EXECUTIVE ACTIONS
FAULT CLEARANCE AT EMITORS; SANITATION IN IMMISION FIELDS; RESOURCE 'MANAGEMENT'; CATASTROPHE SERVICE
LOCAL - REGIONAL PART SUCCESSES IN THE NATURE SPHERE (WITH SETBACKS); ACHIEVEMENTS GENERALLY DECREASED BY CUMULATION OF EFFECTS FROM NEGATIVE ACTIONS ELSEWHERE AND THEIR MOBILITY IN THE ATMOSPHERE AND HYDROSPHERE
PROPAGANDA AND EDUCTION
24
CHECKING
a) IN EXECUTIVE AND IN THE FIELD OF RESULT
b) RESULTS TO ADMIN., LEGISLATIVE, COGNITIVE
25
QUALIFICATION OF COUNTER-ACTIONS IN ACCORDANCE WITH CHECKINGS
DIFFERENTIATED IN ACCORDANCE WITH TIME SPACE AND OBJEKT
26
QUALIFICATION OF ENVIRONMENT RESEARCH, ENVIRONMENT 'MANAGEMENT'
LIMITED TO COGNITIVE FIELD
CONTINUED FOLIO II
= INTER - RELATIONSHIPS
= INFLUENCE
= RELATIVE LIMIT INSIDE THE SYSTEM



Continues from Folio I

① Main task : Optimal environment.' management '

② General principles

- ③ Globality and complexity of environment problems and 'management'
- ④ but :
  - spacial density zones
  - stronly decomposing sectors of reproduction
  - potential centres of reproduction catastrophes
- ⑤ Systems approach to environmental problems and 'management'
- ⑥ Evolution of the Ecosystem
- ⑦ Long-term stability of the Ecosystem
- ⑧ Decision under uncertainty
- ⑨ Environmental protection and formation
- ⑩ Environmental research as part of environment 'management'
- ⑪ Pressure of time and down-to-earth practice
- ⑫ Socio-economic determination and differences in environmental operations
- ⑬ Differences between industrialised and developing countries

⑭ General tasks for an environmental 'management'

- ⑮ World-wide co-ordination of counter-actions
- ⑯ World-wide strategy for global maintenance and cultivation of large environmental sectors and resources (climate, oceans, energy, water)
- ⑰ World-wide practicable tactics for ubiquitius environmental operations
- ⑱ Information system and data bank for environmental information
- ⑲ International system for observation and collection of data
- ⑳ International norming and standardisation
- ㉑ International system of checking counter-actions
- ㉒ Analyses of how national environmental protection systems-work

㉓ Special concepts

- ㉔ Construction of a model of physical environment and its relations to society (Ecosphere-model)
- ㉕ Extent of cognitive counter-actions
  - from new evaluation criteria of economic growth (expansion of reproduction) to technology physical planning
  - from research to execution and checks
  - from detailed to systems research to find complex solutions
  - from deciding praticable social aims to methodology for execution and controls
- ㉖ Social goals (bipolar)
  Protection of resources-Protecting man from environmental damage with optimum extended reproduction of society. Optimality includes environmental protection
- ㉗ Special cognitive goals
  - Use of existing knowledge – Acquisition of more knowledge
  - Definitions of basic categories and relations, specifications
  - Determination of criteria for decision
  - Description of a put-into-effect-system for decisions :
  - • propag.- educ. • legislat. • administr. • executive • checking • control
  - Economics and economy of environmental protect. and 'management'
- ㉘ Substantiation for goals according ㉖ and ㉗
- ㉙ General cognitive steps
  - System analysis – system theory development – modelling and simulation – measures for putting into effect chosen alternatives and checks (projekt 'management'), environmental. oriented technology
- ㉚ Basic cognitive questions of decision
  Continued system of restrictions (prohibitions) and / or (!) new system of actions and attitudes
- ㉛ Organisational principles for research
  - Interdisciplinary national and international co-ordination of research programs (world research program)
  - Research programs orientate towards system solutions
  - Program for research demands throughout the world
  - Specifying priorities of research demands

APPENDIX XI

An Integral Study of Regional System

- MITI Project "Industry and Ecology" -

Hisashi Ishitani and Yoichi Kaya

1. Motivation of MITI Project

Recent rapid economic growth in Japan has certainly realized higher national income per capita, higher standard of living and better social environment (especially sanitary facilities). On the other hand, however, it also has brought about exhaustion of natural resources, generation and accumulation of various pollutants and destruction of natural environment. These phenomena are natural results of having been only seeking after higher economic growth so far, never dreaming that our activities will exceed such a critical level that nature would not be able to recover from the damages or disturbances suffered by them. This situation is considered to be more or less common to all developed countries, but the situation in Japan is strikingly worse because of concentration of population and of industries in a small area and of extraordinary high economic growth. Now that the scale of human activities has exceeded the limit of ecological capacity of the area, planning an integral and, if possible, optimal policy is needed taking effects on both social and natural environments into account. There, however, are two main difficulties in such a planning. The first one is lack of knowledge about the effects of human activities on the nature or even the mechanism of destruction or recovery of the ecological systems. The second problem is lack of appropriate methodology. Quantitative methods used in planning policies so far are not always suitable to investigation of the non-economic problems, for all activities or policies have been mainly assessed from the economic viewpoint.

It is then required to study on the mechanism of ecological systems in order to increase our knowledge in them, and to develop a new methodology in which various aspects of human activities can be dealt with as an integral system. From this point of view, Ministry of International Trade and Industry (MITI) started a three year research project named "Study on Industry and Ecology" in 1971. In this project six working groups are included, of which two study on methodology of an integral system analysis and four on mechanisms of some special ecological problems such as water pollution and heat pollution. The activities of each group are briefly described in the next section.

1-2. Outline of the activities of the working groups

1) Macroscopic study on the structure of Japanese industries and the effects of its change on the basis of a generalized Input Output analysis. (leader, Prof. Y. Shimazu, geophysics)
In this study, a interindustrial and environmental model, that is, a linear static input-output model of industries, natural resources pollutants and social or natural environment, has been developed. Quantitative analysis in the effects of the technical improvement and of various policies on the natural resources and derived pollutants are now under way with the use of that model. In the model, the whole land is divided into twelve districts based on political and geographical differences, and interindustrial and interregional coefficients of input-output matrix for all districts are computed. In addition to the above conventional factors, the rates of the generation of pollutants in industry and consumption and the rates of amount of consumptions of resources that are derived from them are computed, and added into the matrix which then may be called a generalized interindustrial and environmental input-output matrix. The pollutants treated in the model are the total amounts of SOx in the air, BOD

(biological oxygen demand) in wasted water and solid waste. Some other pollutants such as powder dust, NOx, Co, COD and wasted oil are now being investigated but not built into the model yet. The amount of pollutants lessened by installing proper equipments or the effects of activities for decreasing pollutants generation in industries are also to be investigated. The natural resources here included are land space, water demand, labour, oil and coal, iron ore, cupper, lead, zinc, alminium and electric power. Industries are divided into 25 sectors which are aggregated from 42 sectors in industrial statistics. It is true that the results of the analysis represent quantitatively only the present state of the total system, but the analysis can be extended to the future of the system, assuming that we have some knowledge for the future change of this data beforehand.

2) Macroscopic study on a long range planning of a region --dynamic model approach--(Prof. Y. Kaya, system science)

The objective of this study is to develop the practical methods for searching an optimal policy for a region in a general sense taking both human activities and their effects on the environment into account. The target area is Kanto district, the central part of Japan including Tokyo. The model under construction is a dynamic one to which simulation and optimization techniques in modern system and control theory are being applied. The author is the subleader of this project, of which details will be described in the next chapter.

3) Microscopic Study on the mechanism of the heat diffusion process in the social system. (Prof. T. Ojima, Civil Engineering)

The objective of this study is to analyze quantitatively the amount of heat generated by human activities and its effect on the natural environments.

To attain this purpose, a mathematical model of the heat diffusion process in Kanto area is now being made based on the microscopic heat balance eq.. In the model, the whole area is divided into 10 km^2 subareas and for each subdivision the total amounts of generated heat in it are investigated. With this model, the balanced state of the heat distribution and the dynamic state of the heat transfer are now being computed and macroscopic aspects for the whole area will be obtained by aggregating these results.

In the study, the quantitative observation concerning system parameters are the most important to grasp the real situation and attention is paid to this point.

The results obtained by such a microscopic model will give useful information about the causalities between human activities and its effects on heat distribution in the area, and through it, the effects on the climate or the ecological system in the area. Such quantitative results can be taken into the general approach mentioned before.

4) Microscopic Study on the Mechanism of the pollutants in the water and the surrounding soil in rivers and/or sea. (Prof. H. Nishimura, Chemical Engineering)

In this work , the mechanism of the accumulation of the wasted pollutants in the mater (especially in inland sea) are studied based on the practical data observed at Seto Inland Sea. In the observed area, the soil is polluted with only several kinds of materials and this situation has promoted him to study the basic mechanism of diffusion or accumulation of the single kind of pollutant. In this study, the construction of a quantitative model for such mechanism are being made.

II Integral Analysis of Kanto Area

2-1. Objective of the Study

The goal of our study is to get a feasible and desirable policy for the future society, considering not only economic activities (especially industrial activities) but also the surrounding social and natural environment. To achieve this goal, we decided to do a case study on Kanto area, in order to clarify the availability and limit of the conventional methods and to derive the practical methods appropriate for such an objective through the study.

From mathematical point of view, this may be formulated as an dynamic optimization problem, but in practice, this problem can hardly be solved by the conventional optimization technique because of its complexity, the difficulties in collection of the meaningful data or of the difficulties in formulating causal relationship in the system, taking computability into account. These difficulties in the practical work and practical methods applicable for them can only be found through a case study. It is expected that the techniques in operation research such as a simulation, a dynamic optimization, econometric method or Input-Output analysis will be introduced with more or less modification. We intend to investigate the availability of these methods, and then to develop a methodology for such an integral analysis with the use of these.

At the first step, we take the Kanto area as the target area, and then we intend to take other areas in Japan one by one. Finally, we want to obtain an optimal policy for the whole country using these submodels.

The reason why we selected the Kanto area at first are as follows.

1) This is considered as the most typical district showing almost every aspect of the problematique in Japan, where negative effects of over-concentration of the population to Tokyo are very serious.
2) This area is geographically almost isolated from other parts. This is a preferable condition when constructing a model including environmental variables.
3) This area is the economic and political center in Japan, of which the future has a big influence on the future Japan.

The process of our study is shown below.

1) To design and build a "dynamic Kanto area model," in which dynamic causalities between policies, economic activities and environments are formulated quantitatively using all the information now available.
2) To compute the dynamic responses of the model to various policies, and to investigate the effects and the limits of the assumed policies.
3) To check the validity of the model configuration and of the used data by sensitivity analysis. When there are any parts of which change of the parameters will give much influence on the results, validity of these parts should be investigated more exactly and revised if necessary.
4) Throughout the above procedure to develop a practical method or process to obtain an optimal and feasible policy within various constraints.

2-2. Requirements to the Model

When constructing a mathematical model for the real society, it is impossible to formulate the exact causalities of the real system that correspond to the physical phenomina as in the case of modelling physical systems such as servomechanisms or rocket vehicles. It is because the social system consists of numerous components, and the behaviour of each component, especially that of individual human beings, can not be expressed by single mathematical equations. It means that construction of a universal model suitable for any purpose is almost impossible and it is required to clarify what factors we want to explain by the model. From the purpose of our study, requirements to the model will be summarized in the following.

1) The dynamical features of the society should be expressed by the model so that we may obtain a desirable policy for the future. Considering that there are a lot of delays or lags existing in social system, the dynamic analysis is essential to our purpose.
2) If there exist any causality loops very sensitive to the system behaviour, these relations should be formulated as accurately as possible. The quantitative evaluation for these mechanism are very difficult because of the lack of suitable data, and we can only observe the balanced results of such loops. If we want to search an optimal policy for the future, the mechanism of such loops may also have to be improved by the policy. Therefore these causalities should be expressed in the model, introducing assumptions for the configuration or values of parameters.
3) Relation between human activities, especially administrative control such as governmental and private investments or consumptions and natural environment, should be included

in the model.

Though these effects have been scarcely considered so far in the economic planning and there is little knowledge about these relations, these are indispensable parts in our study.

We desire to deal at least with the following features or events.

(1) States of air pollution, water pollution, soil degradation by furtilizer and solid waste.

(2) States of utilization of land and water resource.

(3) States of transportation and regional distributions of population and industries.

(4) Constitution of industries in the area.

(5) State of social environment such as housings or other social overhead.

(6) Effectiveness and limiting factors of various policies.

(7) The relation of the Kanto area to the whole country.

2-3. Basic Philosophy in the Model Building

When it becomes necessary to grasp and represent causalities between human activities and social or natural environments, the regional distribution of economic activities should be taken into account which give a great impact on the local environment, because the severest part in the area reaches its local limit before the total area will reach its average limit. It should also be considered that existence of inequalities or social gap sometimes causes social unrest. However, there exist some imbalances in population density or economical activities in any region, unless we consider very narrow part in the area. And for such part, the system equation does not exist, because system behaviour for the part is influenced from other parts and therefore cannot be described by the variables in the system.

This situation reminds us a simple method to divide the area into several parts and to construct submodels corresponding to these parts and then to combine these together to total system used in the analysis of diffusion process such as heat transfer or ocean current analysis. But such a method can be hardly applicable to our problem because of the following difficulties.

1) Difficulty in collecting the data about subsystems and their interrelations.
2) Difficulty in finding causal relationships in subsystems because of disturbances from other parts. (Any activities in one part are not independent of those of the other parts and so are not determined in the subsystem.)
3) Difficulty in computation of optimizing a large scale model.

In order to overcome these difficulties, a social system in the area is divided into following three parts which constitute a hierarchical structure.

A: a part directly influenced from external region. (Causalities cannot be expressed only by internal variables.)

B: a part in which variables correspond to quantities summed over the area.

C: a part in which variables are manifestable of internal distribution of quantities.

Then it is adequate to construct the following three level hierarchical model.

A: a model for outer region. (or for whole country)

B: a model for an aggregated system for the area.

C: a model to manifest a distributional behaviour in the area.

With these submodels, the objective social system can be analyzed in the following way.

1) In model A, the total amounts in the whole country and their optimal distribution in the country are presented neglecting other submodels. With this model, the desirable distribution in the country will be obtained within dynamic feasibility.

2) Outputs of model A are used as exogenous variables in B. Here the variables related to internal states of the area or internal criterion and constraints can be dealt with except their internal distribution. We call a model of this type an unilevel model.

3) In model C, distribution of some representative variables in model B are considered. Total amounts of variables in the area are given from model B and distribution of these quantities in the area will be determined or analyzed by optimizing some given criteria. The average values of the variables in the area may, in turn, be used in model B.

These three level hierarchical models are connected in the following way, though the work is still under way.

1) At first, we construct the unilevel model so that we may grasp the dynamic characteristics of the objective area. With it, the dynamic feasibility and the effects of the policies can be discussed so far as they are concerned with the total amounts of variables. At that time, the appropriate assumptions for the exogenous variables are made, given the future goal in Japan.

2) Next, the distribution model of type C is constructed so that we may discuss the distribution of variables in the area. The step we took first is division of the Kanto area into two parts, the inland area and seaside area. We are now providing more detailed submodels to discuss the distribution of variables by dividing the whole Kanto area into seven prefectures. These submodels are to be connected to the unilevel model, and be used to represent the distribution of investment or population among these subareas. Only by such a division transportational aspect of the area can be clarified. In this way, the models C are merged into the unilevel model. But the policy for the optimum distribution can be obtained in model C within the constraints given by Model B. In such sense, these two models may constitute a hierarchical structure.

Another possibility in the model building is to construct two independent dynamic models of type B and C, and to run these two in parallel,exchanging necessary information to each other. Thus, the information for the total amounts of the variables determined by the optimization procedure of the whole area will be given to C, as the constraints for the distribution. On the other hand, the parameters of model B will be modified by the results of model C. But this method needs very difficult algorithms to keep these two in a consistent way, and so we have decided to try the former type of model building.

After the distribution in the area is decided by this model, we intend to discuss the feasibility from the ecological viewpoint with the help of some ecologists, not by the use of any mathematical tools.

3) Finally, the total model of type A will be constructed which

represents the whole country, and the desirable future, including the distribution in the country, is discussed and planned. There also exists a difficulty in connecting this model to other model without any inconsistency, but it will be overcome by the use of the similar method as described in the preceding step.

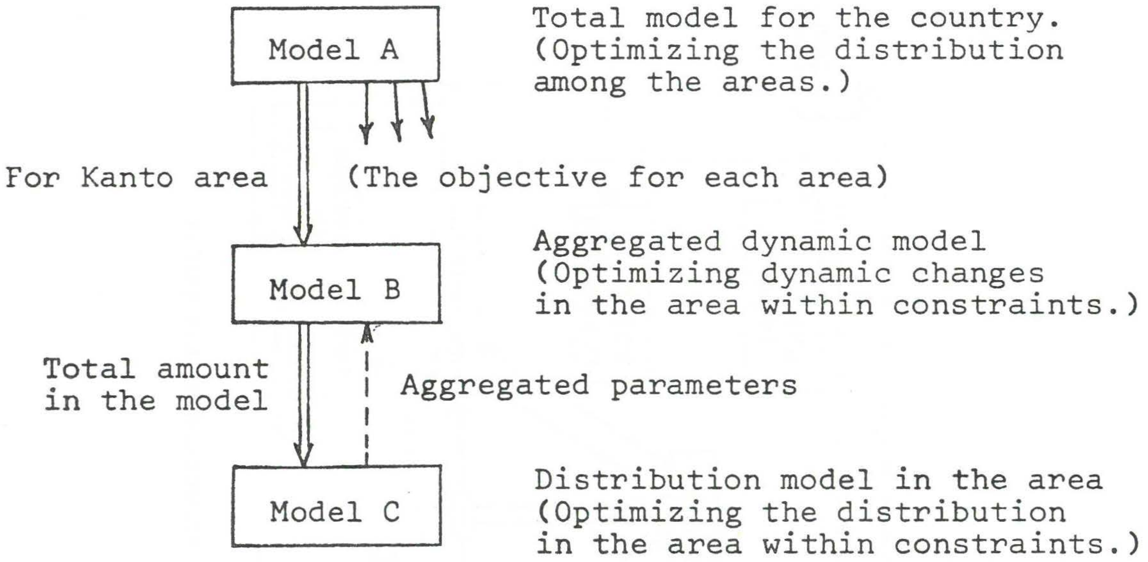


Fig. 1. Interrelation of Submodels

2-4. The details of the Unilevel model for the Kanto area.

The basic structure of the model is shown in Fig. 2. Essentially this is a dynamic mathematical model including broader parts than that included in usual macroeconometric models. The system behaviour is described by difference (differential) state equation as in the model used in the control theory or in System Dynamics, and therefore every interrelation among the system variables is represented by input-output equations. Simultaneous equations that appear in econometric models are avoided for the following reasons.

1) Computational constraints (As the system becomes inevitably

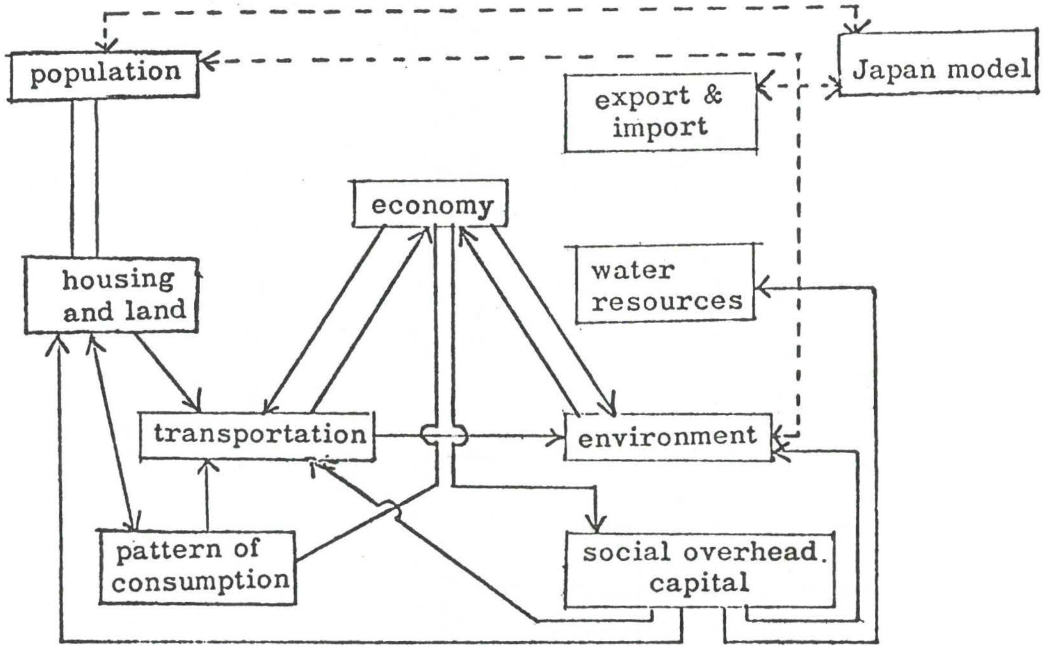


Fig. 2. basic structure of the model

nonlinear, it is difficult to solve the simultaneous equation.)

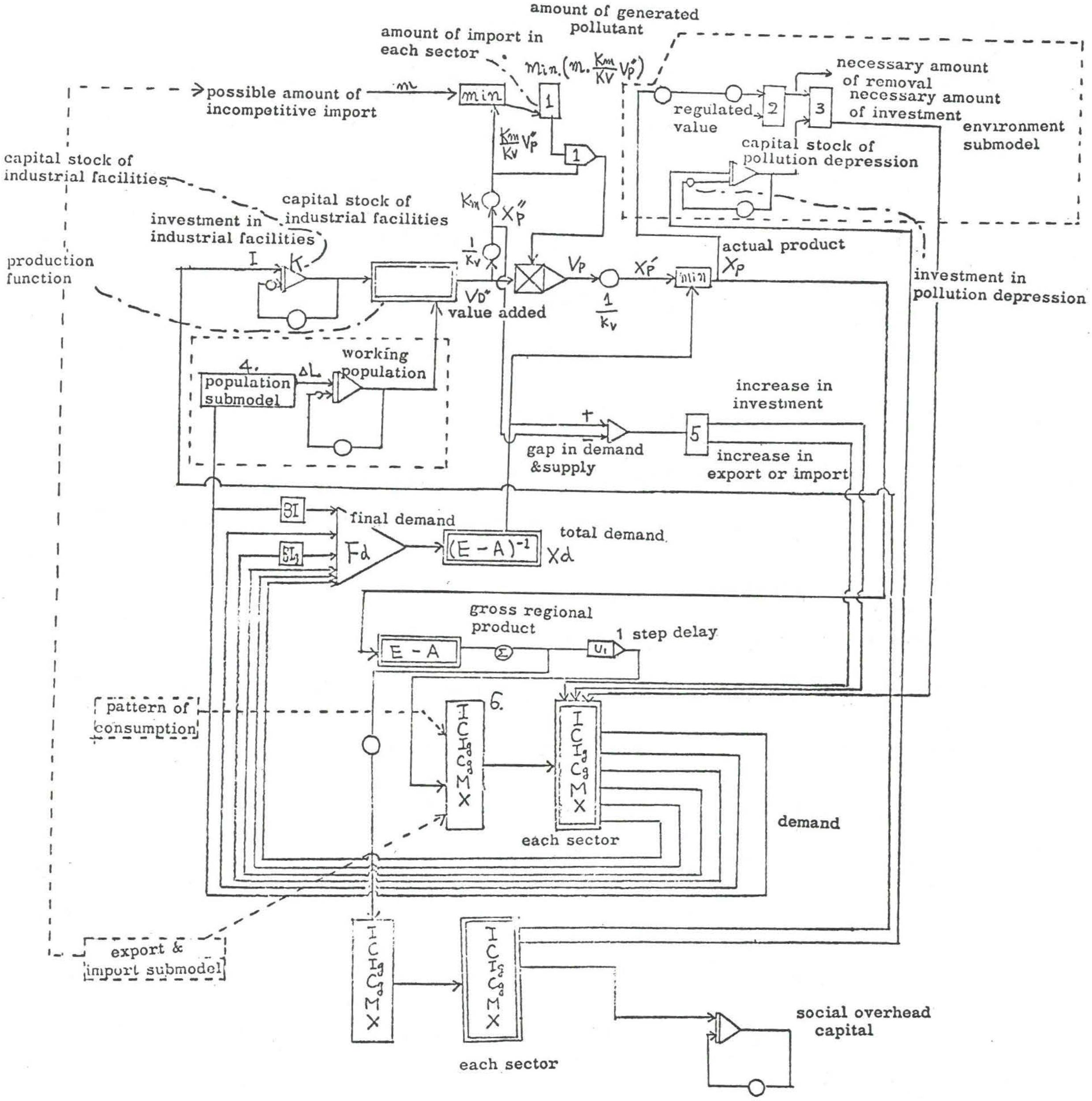
2) To simulate the causalities in real society as much as possible and to see what part of the system will reach its limit at first, and how it affects in the system.

In the model, the state variables are limited within the physical or political constraints. This structure is suitable for long range planning where it is required to know what sort of physical constraints will become serious for assumed policies: The available data or information is used in the appropriate form, and when the proper data does not exist for the essential part in the model, some appropriate assumptions or policies are introdued. As a rule, parameters are estimated from real data from the last 5 years.

As for the exogenous variables that should be determined by the total model of type A, some assumptions are made refering to the other informations already obtained by previous researchers and now available for our study. These variables are as follows.

1. Influences of change in the variables of the external regions. (material flow, the limits of export or internal transportation)
2. Variables that are controlled by a policy (industrial constitution and allocation,the limits of population inflow.)
3. Technical innovation and its influence, revolutionar change in the measures of values, etc..

The detailed structure of the unilevel model is shown in Fig. 3. In the model, the industrial section is the most significant and is located in the center. Although this section is almost the same as an econometric model, the configuration of this model is fundamentally different in the following points.



K_v: rate of value added

☐ policy

K_m: rate of demand on import

1. distribution of goods of incompetitive import
2. determination of necessary amount of removal of pollutants
3. Determination of necessary amount of investment in pollution depression
4. population submodel with imigration policy

Fig.3. Block diagram of the model.

1) In order to discover a desired industrial policy by investigating the effects on environments, all industries are separated into the following 8 sections according to the differences in structural parameters or their effects on natural environment.

   (1) Agriculture and Fisheries.
   (2) construction.
   (3) Raw materials processing industries.
   (4) Assembling industries.
   (5) processing industries other than (3).
   (6) Services, commerce and finance.
   (7) Energy. (Electricity, Gas)
   (8) Transport and Communication.

2) The Demand-Supply gap is computed in the model, from which it is decided to encourage (discourage) investment for the next year or to decrease (increase) exports. It is determined quantitatively by industrial policies that are assumed in a simulation run.

Other characteristics of the model will be summarized as:

1) The supply is determined by the Production Function of a Cobb-Douglas type. (computed from Labour, Capital and residual term.)

2) The Demand is determined by kinds of Consumption and Investment Functions. (computed from realized production in the previous year and the growth rate)

3) Realized production is determined by the minimum value of the production capacity, the constraints in imports or other natural resources and the allowable level of industrial waste. (Supply Oriented Model)

4) Policies assumed in test runs will be shown later.

5) To explain the interrelations among industrial subdivisions, input coefficient matrix A is used, which alone is considered as only present available data showing these causalities. Since A is derived from static data analysis, predictable changes in A must be considered for the future.

6) A change in the final demand composition in the GNP cannot be explained by the variables in the model. Then some probable patterns in the future are used as exogenous variables.

7) A change in the composition of household expenditure is also assumed and used in the model.

8) As representative pollutants to be controlled below the predetermined level by policies, the total amount of $SO_2(SO_3)$ generated in the area and BOD (biological oxygen demand) in draining from industries are considered and built in the model. In each case, the pollutant generating rate of each industry (generated amount of pollutant/output measured in value added) is used in order to compute the pollution level. When the level exceeds the limit, this is lowered by increasing an investment for pollutant preventing equipment or decreasing production. As the cost and efficiency of the equipment, present values are used. (which will be overestimates for the future.) For SO_x, total allowable amount of generation corresponding to the environmental control level is computed, assuming that the present regional distribution of industries will continue.

9) The investment and stock of social overhead capital is computed, but a feedback loop for a policy is not built.

If the distribution of the stock is known in the model, the influence on life-environment can be shown and hence a required policy will be obtained.

As for the exogeuious variables mentioned before, the following policies was assumed in the simulation runs.

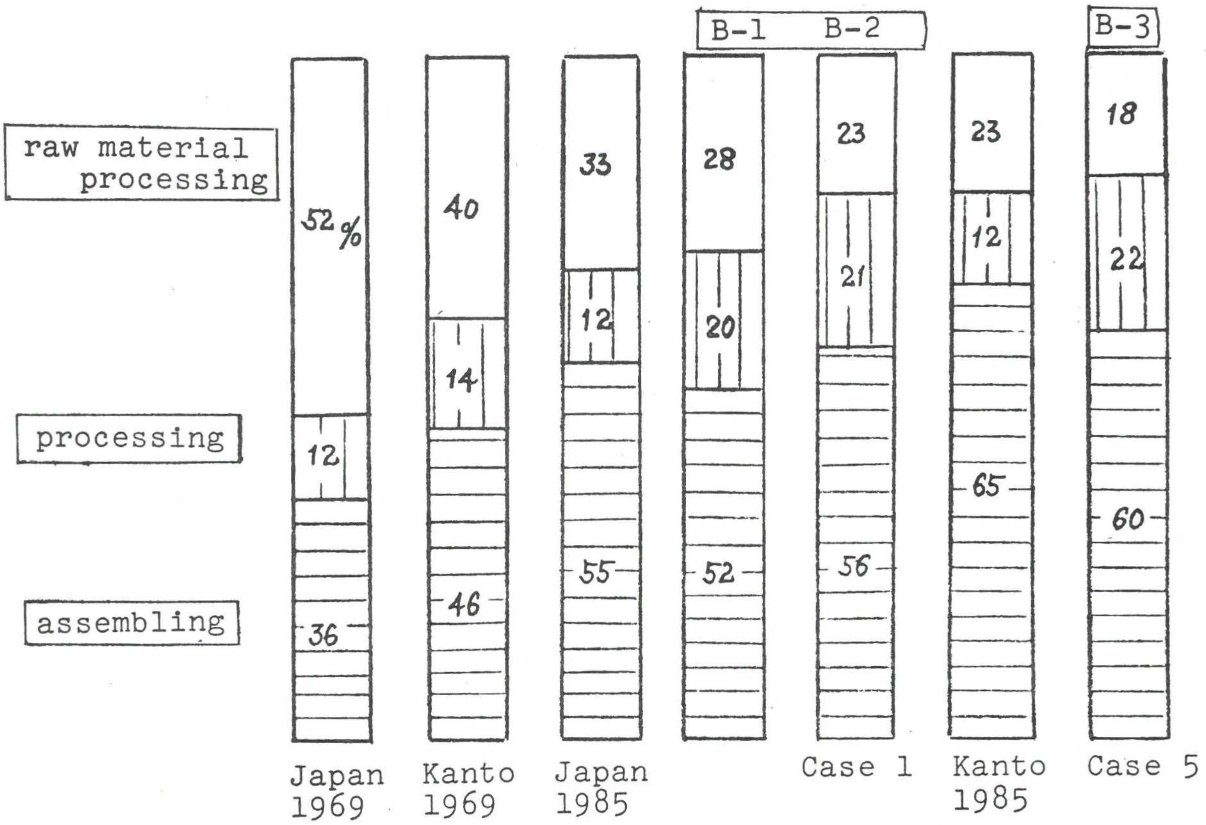
1) A change in final demand composition in GNP cannot be explained by variables in the model. Then some probable patterns in the future are used as exogenous variables. (shown in Table 1)

Table. 1. GNP composition by final demands

	A-1	A-2	A-3
personal consumption	54%	50%	55%
government current purchases	9	7	6
government fixed capacity formation	8	9	14
equipment investment by private enterprises	20	23	15
private housing	5	6	7
change in private inventories	4	4	3
current foreign surplus	0	1	0

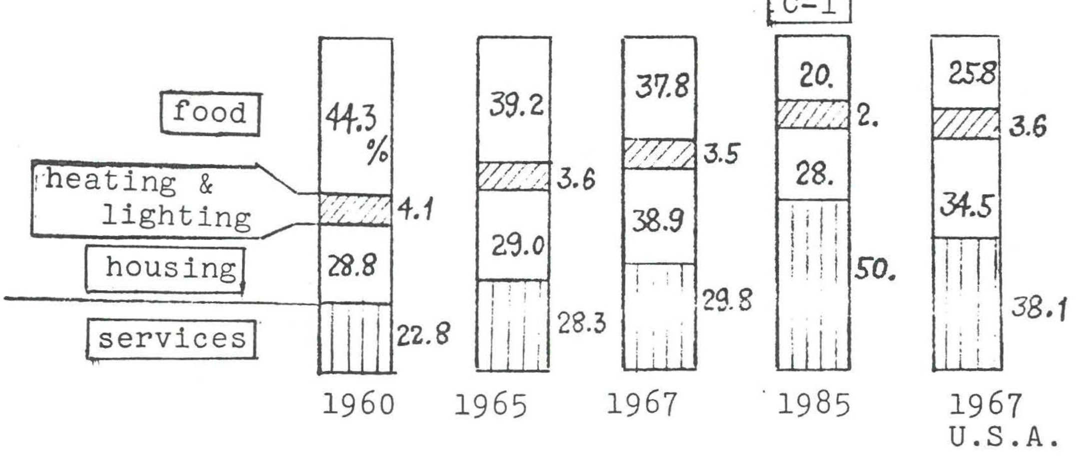
2) The policy to convert the constitution of industries in the area are also assumed. The data is based on the results of the work of MITI, and shown in Table 2. This policy aims to lessen the shares of processing industries and increase that of assembling industries instead.

Table 2. Constitution of Industries.



3) A change in composition of household expenditure is also assumed and used in the model, and shown in Table 3.

Table 3. Household expenditure



These policies are combined in the following way, and for each case simulation run for 30 years is computed starting from the year 1965.

Case 1. Standard run.

1) Assimbling industries are increased instead of Raw material Processing industries by policies.
2) Governmental Fixed capital is increased.
3) Inflow of Population is controlled below 200,000 person/year.
4) Pollutant generation is controlled.

Case 2.

Pollutant generation is uncontrolled.
Other conditions are same as in case 1.

Case 3.

Present GNP Composition continues without any any change (Private equipment investment is greater than that in case 1.)

Case 4.

Inflow of Population is not admitted.

Case 5.

Raw materials processing industries are suppressed severer than in Case 1.

Some of the results are shown and compared in Fig. 4 or in Table 4.

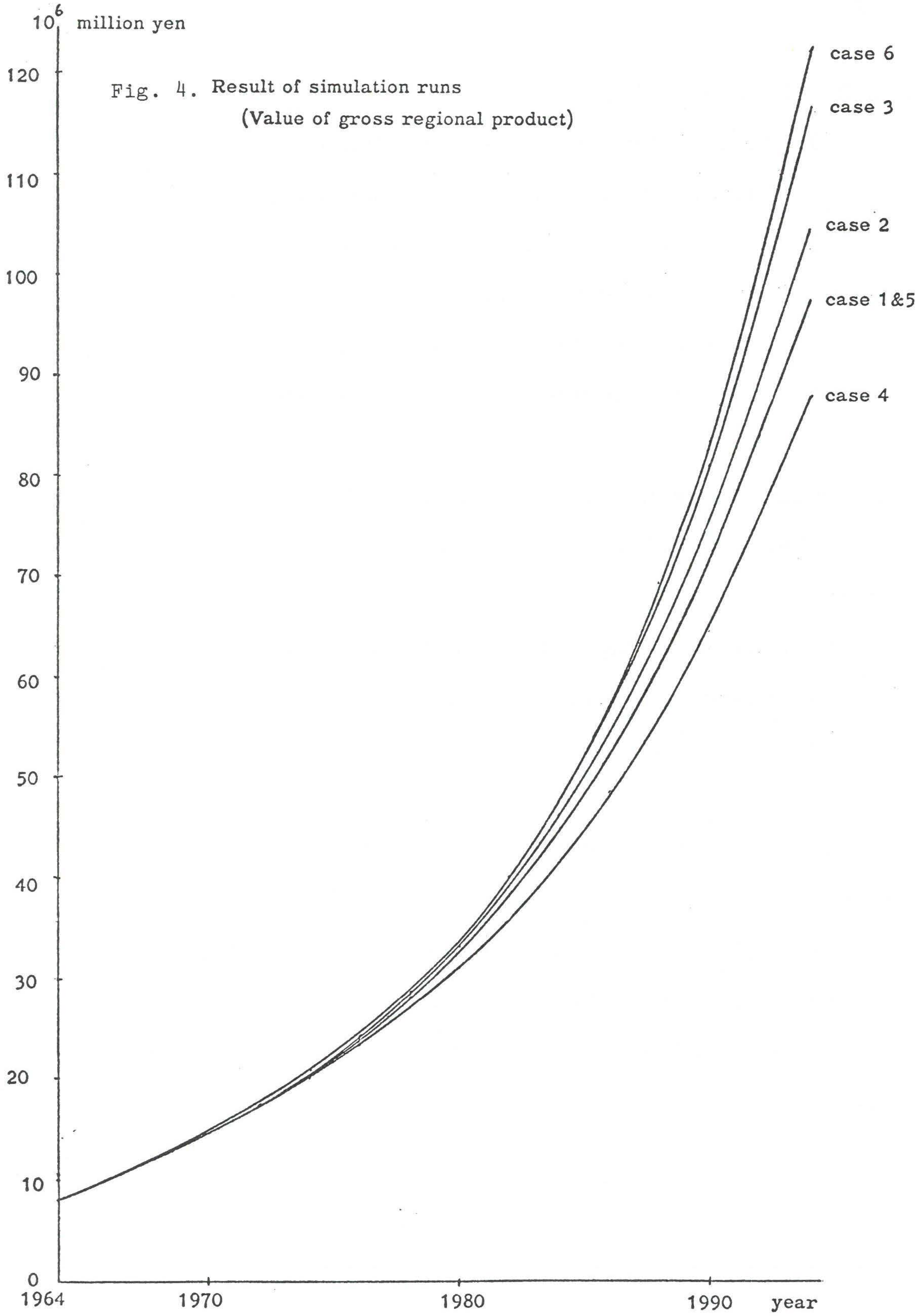


Fig. 4. Result of simulation runs (Value of gross regional product)

cases	combination of policies				order of economic growth	order of environmental level	order of capital stock of pollution depression
	A	B	C	D			
1.standard case	A_1	B_1	C_1	D_1	4	2	2
2.case without pollution control	A_1	B_1	C_1	D_2	3	5	
3.case of priority to private investment	A_2	B_1	C_1	D_1	2	4	1
4.case of suppression of population concentration	A_1	B_1	C_2	D_1	6	1	3
5.case of priority to intelligent intensive industry	A_1	B_2	C_1	D_1	4	2	4
6.case of priority to private investment & without pollution control	A_2	B_1	C_1	D_2	1	6	

Table 4. Several cases of simulation run

Generally speaking, these results show the very reasonable trend and it seems that there are no sign that indicates the existence of fatal defects in the model. We have concluded that the configuration of the model may, at least fundamentally, be appropriate to investigate effects and feasibilities of various policies in a dynamic manner. There still remain several issues to be solved, one of which is concerned with validity of the available data, and we continue to do effects for the better model.

2-5. Two Region Model for Kanto Area.

The unilevel model can only deal with the features explainable by the total amounts of the variables in the area, but the distribution of production and other variables in the area is considered as important as their total amounts summed up over the area. In reality, the inequality of the distribution in the area is becoming more remarkable because of the overconcentration into the seaside region including Tokyo and the surrounding industrial areas. It necessitates construction of the distribution model with which effectiveness of the policies concerned with distributional problems may be investigated. As the first step 2 region model has been constructed, which is an extension of the former unilevel model. Its skeletal structure is shown in Fig. 5, where the parts denoted by double rectangles are those consisting of two region submodels. The structure of the model is basically similar to that of the unilevel model, and the elements of the raw vector corresponding to transportation of the input output matrix (for the whole area) are modified by the distribution of productions in the two regions.

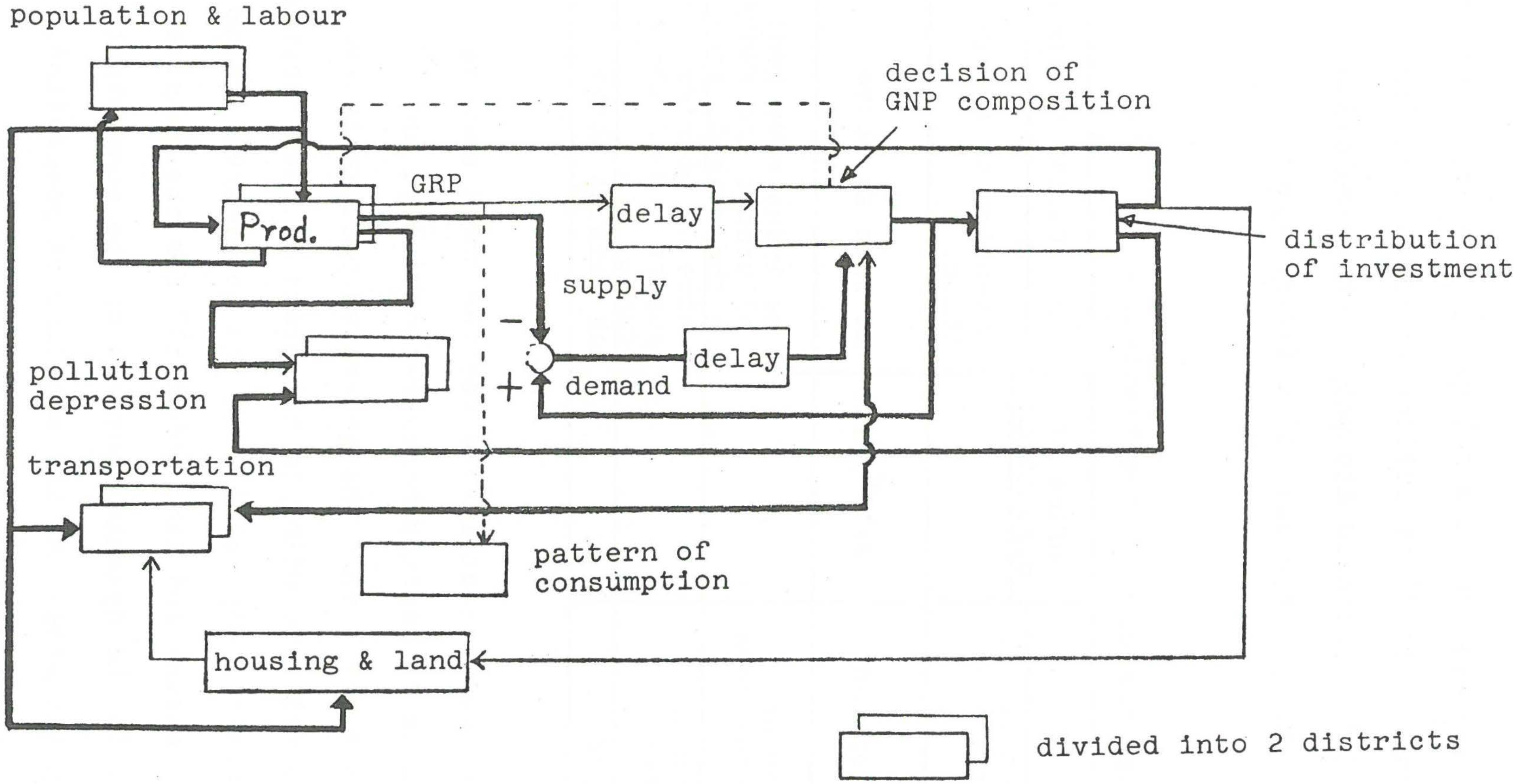


Fig. 5. The block diagram of the two districts dynamic model

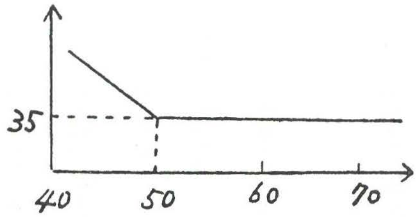
The simulation was made for the following 5 cases, in which the policies relating to the distributions in Kanto area are mainly considered. Other policies assumed in the simulation runs are the same as that in the case of unilevel model.

Table 5. Assumptions used in the Simulation

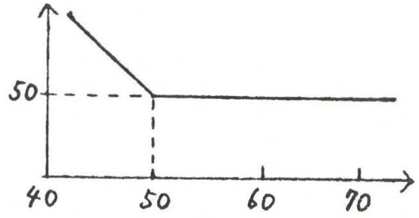
Cases	Inflow of population	Constitution of Industries
A Case of suppression of population concentration into Kanto area.	0	Extension of the present state.
B Standard case. (Extension of the present trend.)	2x10^5/year	as same as above
C Case of suppression of growth in the seaside area.		The industries generating pollutants are supressed in the seaside area
D Case of suppression of growth in Kanto area.		Above industries are suppressed in the whole Kanto area
E Combination of C and D.		as same as above

In this case the constraint levels for the total amounts of pollutants are given for each subarea respectively, and shown in Fig. 6. This means that the generated pollutants are constrained independently according to the state of each subarea, and this is more practical way to discuss the local environment.

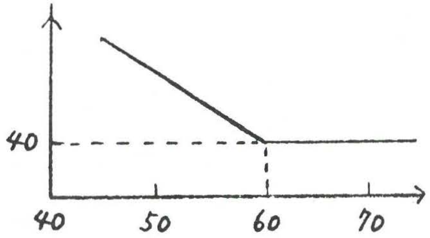
In the model, "housing and land submodel" for the seaside area is made to explain the dynamic features of the concentration of the population in the area. As the mobility of population consists of very complex factors such as individual desires, local environments in the society, the state of the family configurations and cost of lands, it's almost impossible to construct a mathematical model based on the real causalities.



The total amount of
S in the seaside



The total amount of
S in the inland



The BOD in the water

Fig. 6. The constraint level
for the pollution

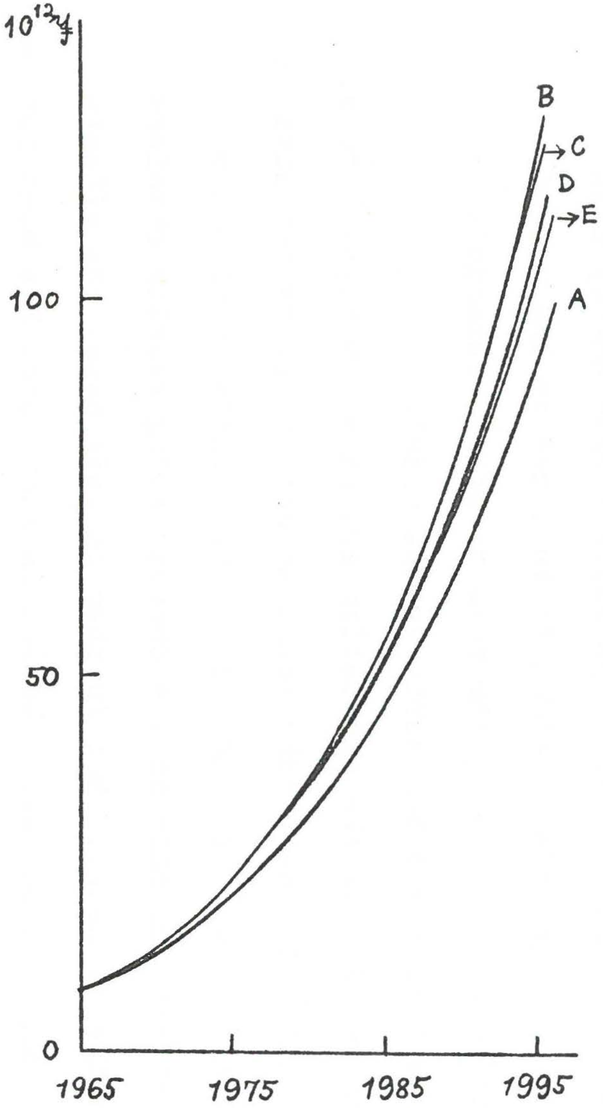


Fig. 7.

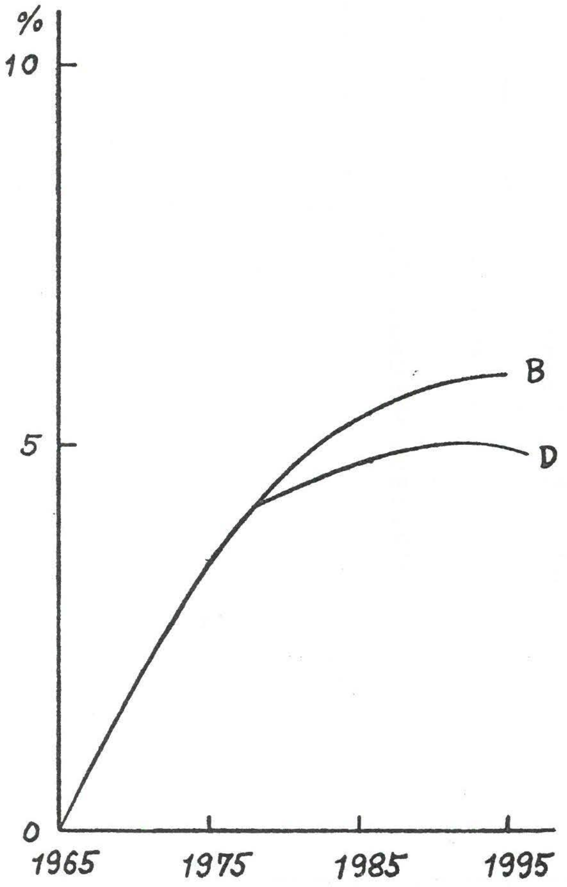
Value of gross regional product in Kanto
(computed with 2 districts dynamic model)

Therefore, this submodel becomes rather a conceptual model described by mathematical equations, and some assumptions are used to explain the average tendencies or causalities of human behaviors of which parameters have hardly been obtained. Though this submodel is included in the 2 region model and runned together, the results of the submodels is not fed back to the other parts in the model.

Some results of the simulation are shown in Figs. 7 to 9. In Fig. 7, the trends of the total amounts of gross products in Kanto obtained by this model are shown. These results are quantitatively the same as the corresponding results obtained by the unilevel model. But further in this case, the effects of the changes in the distribution in Kanto area has been obtained. The resultant shares of products and population of each subareas are shown in Fig9, 10 and Table 6.

The total amounts of the pollutants generated in each subareas are computed based on the results obtained by MITI research team (the workin group for generalized input-output analysis). The results are shown in Fig. 11, and these also show the effects of the change of the distribution.

These results only reflect the meanings of the assumed policies, but it is assured mathematically that these states of distribution are dynamically feasible and we can realized to the level of such states within constraints upon condition that assumptions used in the model are not fataly incorrect.



The ratio of capital stock
of pollution depression
Fig. 8.

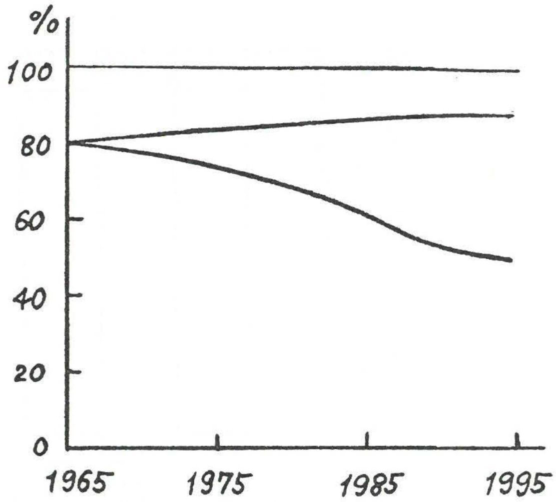


Fig. 9.

The ratio of population
in each district

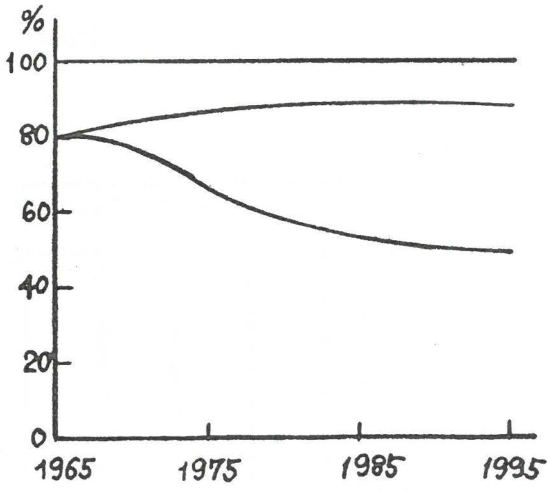
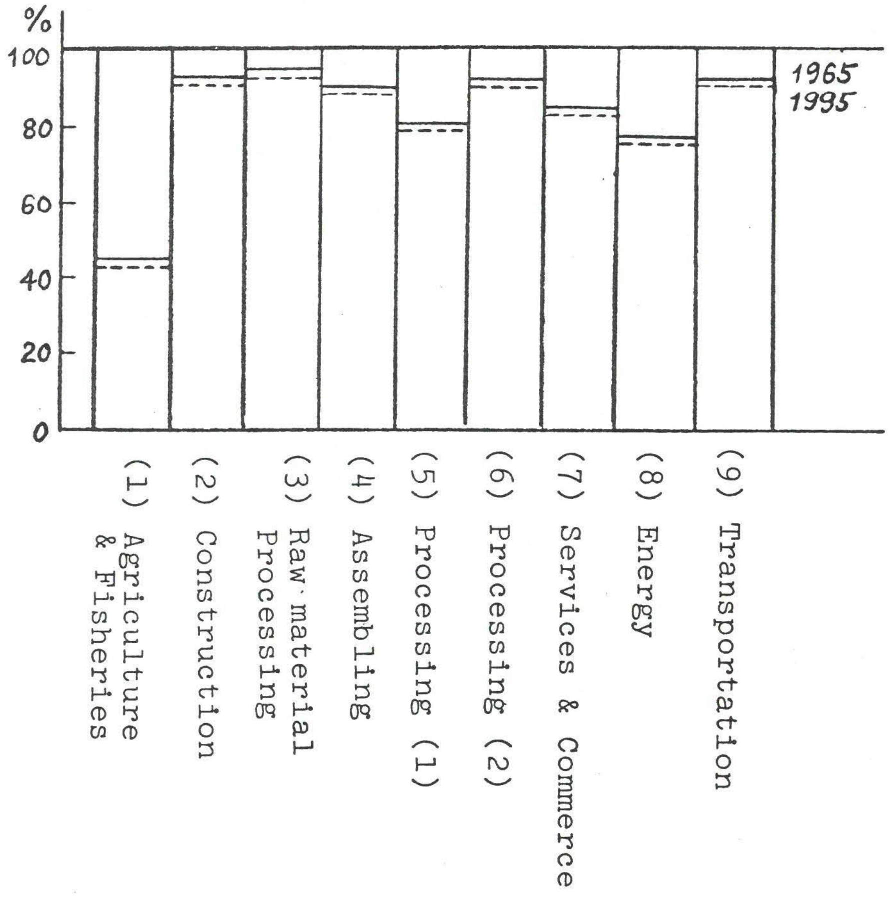


Fig. 10.

The ratio of gross product
in each district
(upper part is the inland
and lower is the seaside)

Case B



Case C

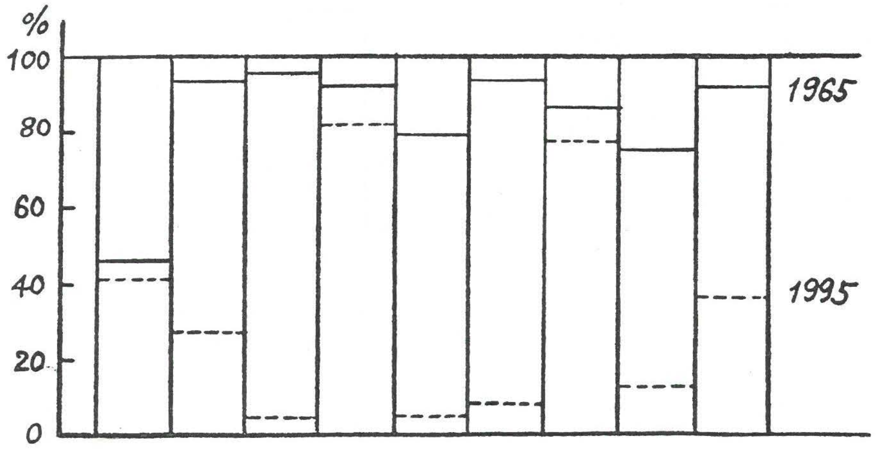
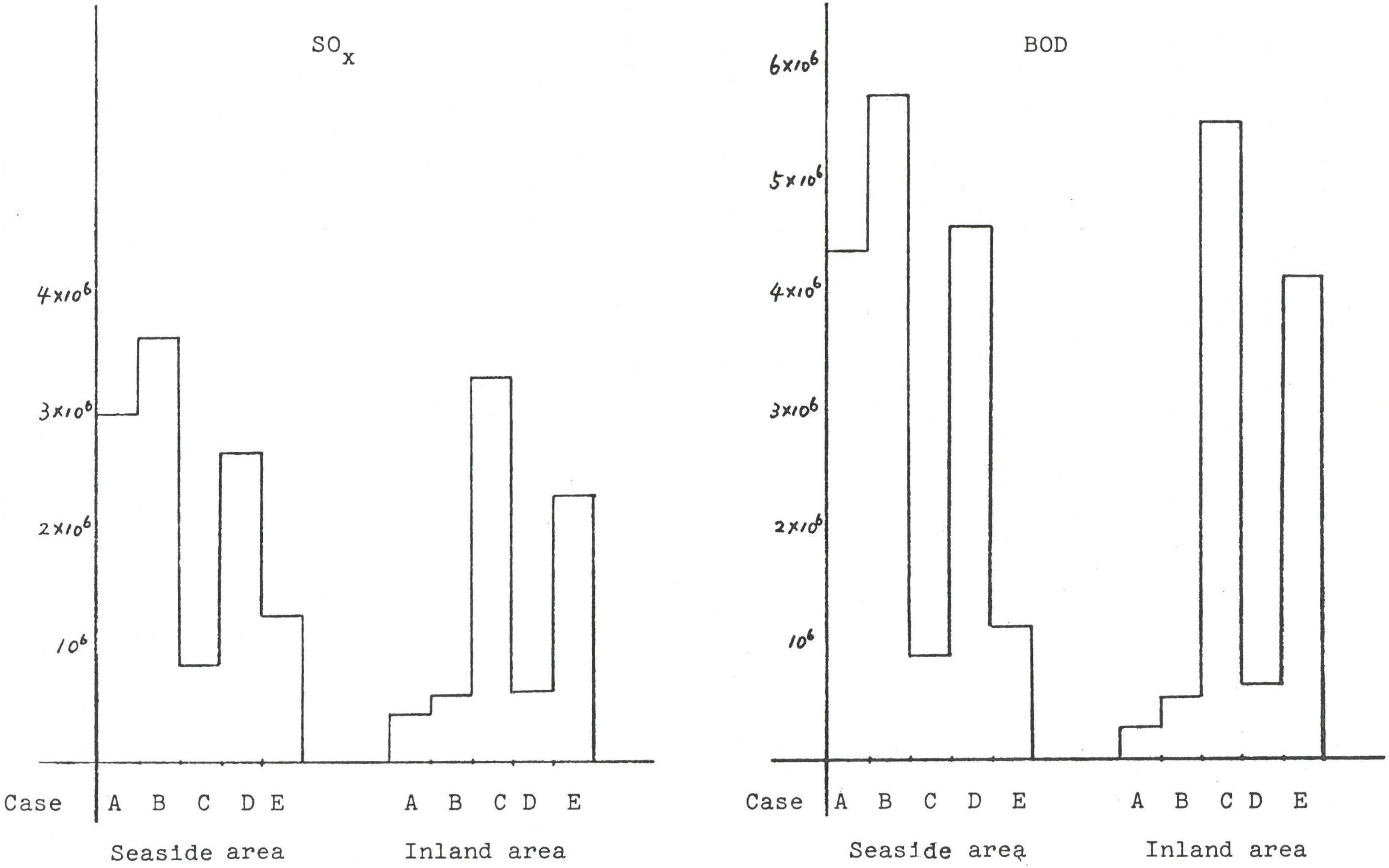


Table 6.

The change of the ratio of product in each district
(upper part is the inland and lower is the seaside)

Fig. 11. The total amounts of generated pollutants in each subarea.



III Further Approach

The work is now in progress and there remain many issues concerning the validity of the used data and model configuration. The temporary objective, however, is not to construct a perfect integral model of the area but to develop the methodology for long-range planning of a society taking both economic and environmental aspects into consideration. The models so far discussed are of types A and B and yet too crude to investigate the possible and desirable production pattern over the area, of which the analysis requires a model manifestable of production distribution in the area. A primitive solution to this difficulty is to divide the area into several subareas and to construct a model consisting of the submodels, each of which represents each subarea. Such a model is naturally very complex and does not afford computation for dynamic and optimal planning.

Another solution which seems more practical is to modify the unilevel model in the way that the part of production is divided into several submodels corresponding to the subarea. The variables in the model related to transportation are determined as the functions of the production distribution over submodels. The investment or population in each submodel is to be determined so as to optimize a criterion function including the terms related to production density per area, to income gap among the subarea, to the total amount of transportation in the whole area and to the environmental constraints specific to the subarea. Mathematical programming methods such as the quadratic programming method and the gradient method are to be employed to do such an optimization. It is noted that the optimization described in the above is not to optimize the model behaviour in the long run but of the next year (or term), one by one. The overall long run optimization of the whole model will be obtained as a modification of the above results. (The above procedure has been experienced in the other project the authors are now engaged in, and the results are successful.)

Apart from this project, the authors have also started to construct a dynamic model for Kinki area that is the other economic and political center in Japan including Osaka, Kyoto and Kobe. In this study, we intend to construct the model of the same structure as the Kanto model so that we may compare these two models quantitatively.

With a model of this type, the human activities in the area can be discussed from an overall point of view. Comparison of our approach with conventional methods reaveals the following significant differences between them. The conventional models the most related to the purpose of the project are the econometric model and the turn pike model. Both of them are useful for short-range planning of economic activities of a society, but not for a long-range planning of the whole activities.

The second difference is that structures and parameters of these conventional models are determined after statistical processing of the past data, while those of our models are partly through bald assumptions or according to our intention for the desirable future. It is important that a long-range planning is inevitably based on the planner's intention for the desirable future and his intuitive knowledge for the future society. The long-range planning models should not be a tool for a single extrapolation of the past trend but a tool for explaining the planner's intention in a logically consistent way. Considering that what we can obtain from the society as the data is very few except those of the past economic activities and that a long-range planning of the society is a neccesity, there seems no other way than our approach. The validity of such assumptions or consistency of the overall plan can be evaluated by sensitivity analysis.

There are several other minor differences--existence of long time delay in the model, use of dynamic causal equations in place of simultaneous equations, use of non-linear dynamic optimization method, and so on---but are not described here in detail.

APPENDIX XII

Environmental Systems Control

- A Systems Approach -

Masa-aki Naito

* As a major subgroup of the project "Environmental Pollution Control" (EPC) in progress, Dr. Sawaragi's group is conducting a research from the systems engineering viewpoint and is going to extend the present subject.

* This is an introduction of the outline of what Sawaragi's group is presently carrying out concerning environmental problem and is going to do at the next step.

* "Environmental System" defined herein is illustrated in Fig. 1. Two serious problems which have come out in recent years in this system are

(1) Depletion of Natural Resources

(2) Environmental Disruption

which appear as the beginning and end points of the flow of goods as seen in Fig. 1.

* To cope with these two bottlenecks, the following three countermeasures would be plausible,

(1) Decrease the flow rate of goods

(2) Change the flow diagram

(3) Minimize the bad effect by means of "Environmental Pollution Control".

The problem (3) is the one on which systems engineers can work and with which the project "EPC" is mainly concerned. The extension, however, should be made to take the former two strategies, (1) and (2) into consideration together with (3) in order to attain a true solution of environmental pollution.

* The complicated system as the object of the Environmental control may be summarized as in Fig. 2-A. Fig. 2-B is an interpretation of the system in Fig. 2-A from the viewpoints of process or control engineers.

* The subject with high complexity and with wide variety herein is classified featuring several facets of the characteristics involved in the system. This is figured out in Fig. 3.

* Examples of the themes generated from combining subsystems in terms of three major axes (X, Y, Z) are as follows.

(1) Renovation of production system to minimize waste generation,

(2) Allocation and control of pollution sources,

(3) Planning and operation of treatment systems,

(4) Design and control of treatment processes,

(5) Evaluation of the effect of environmental degradation.

Our major concern is in the theme (3) among these. All the other themes have more or less interaction with the theme (3) providing information in their own particular manner as shown in Fig. 4.

* As the next stage of the work, we will extend the area of the work to cover the theme (1), (2), (4) and (5), i.e., to take the Production and Municipal systems into consideration with equal weight to Treatment system and Environment.

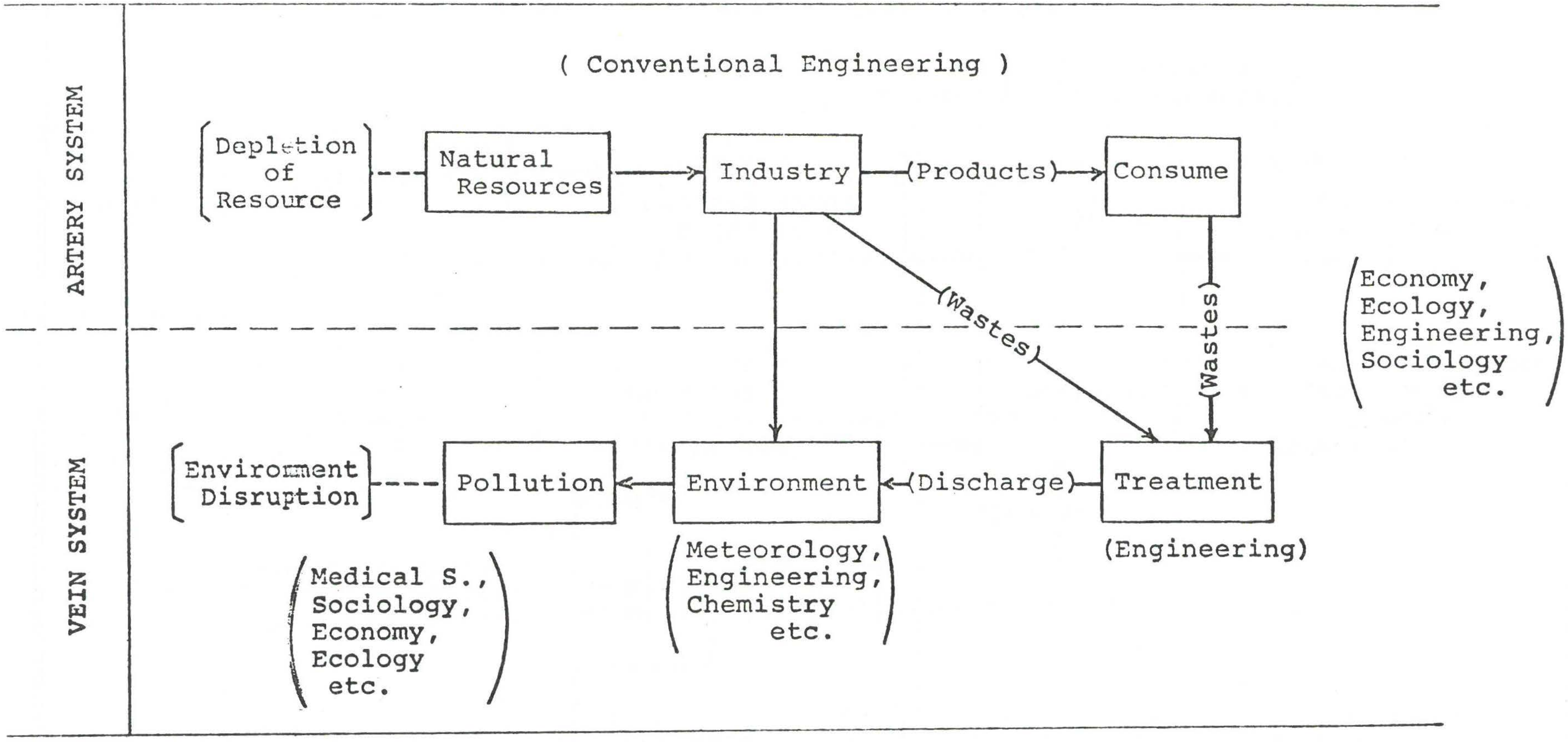


Fig. 1 Overall View of Environmental Problem.

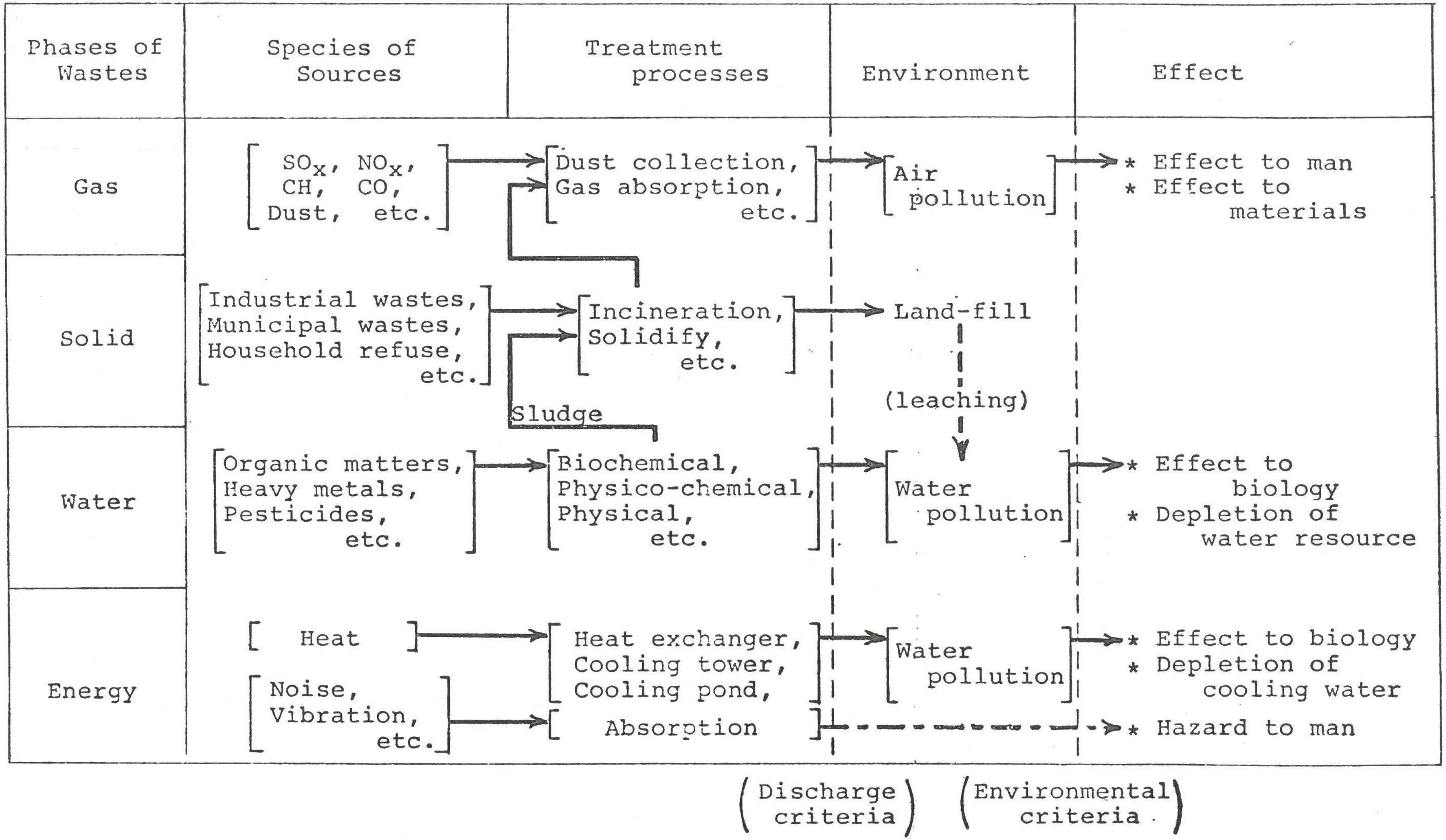


Fig. 2-A Unified Expression of Pollution due to Various Phase of Pollutants.

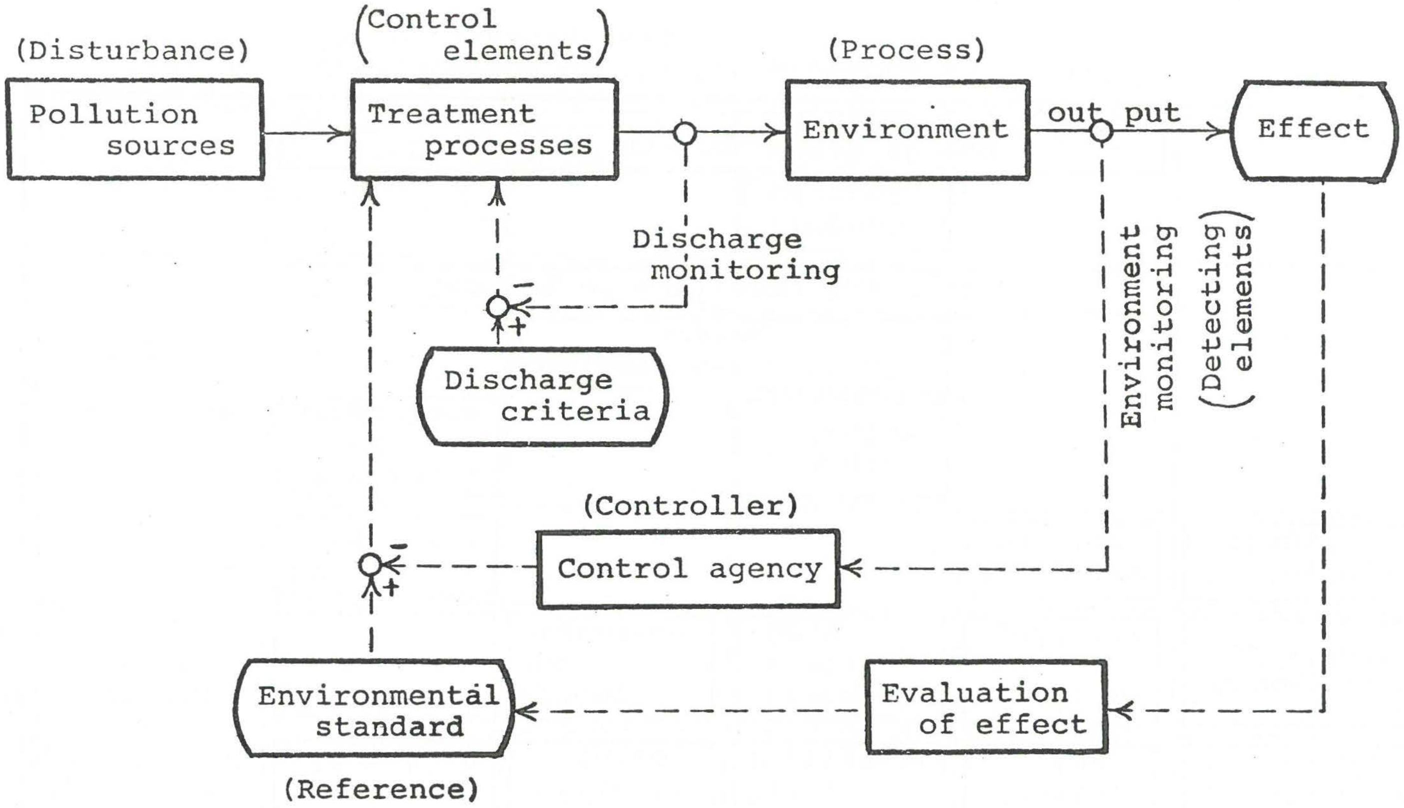
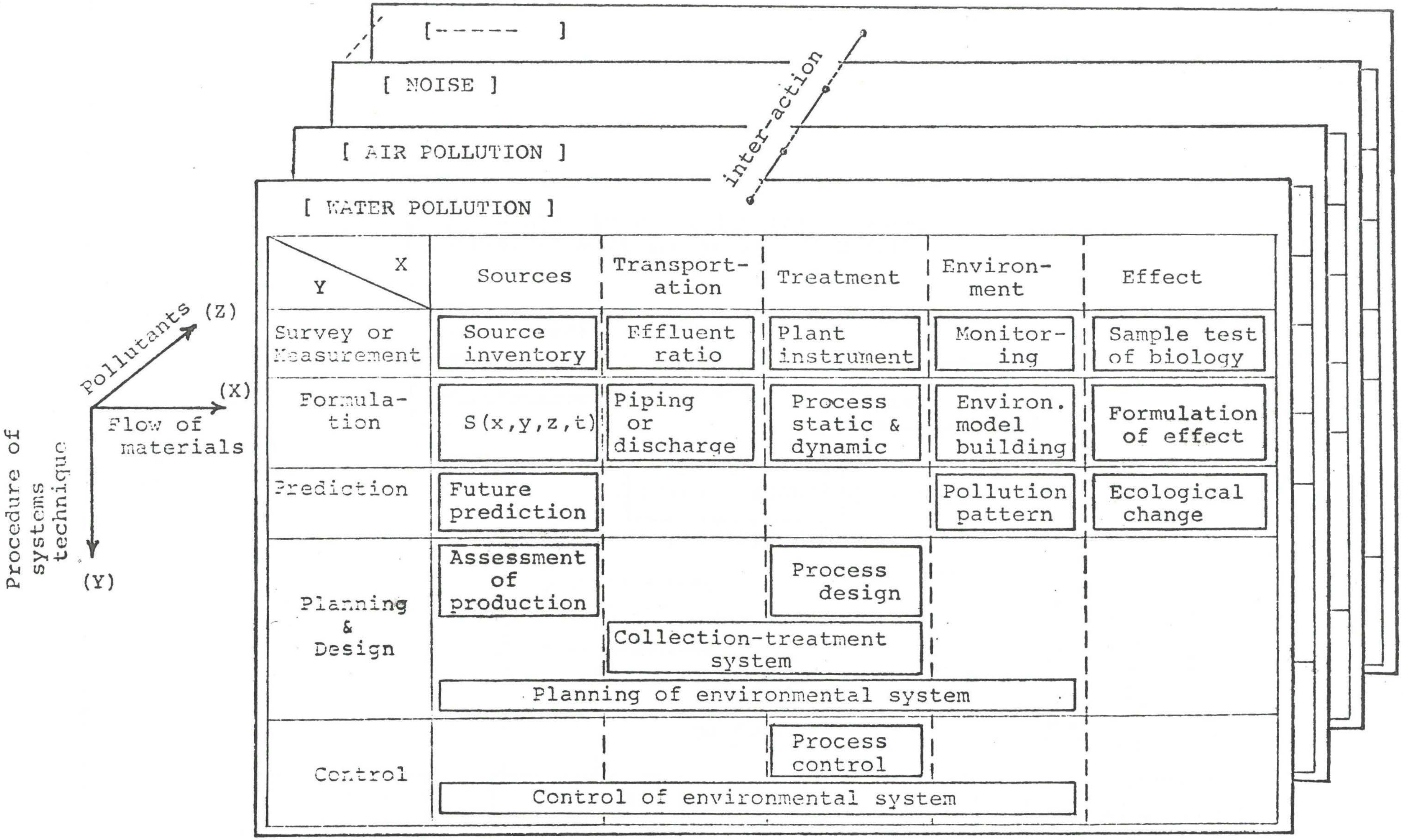


Fig. 2-B Interpretation of Environmental System from the View Point of Control Engineers.



X Y	Sources	Transportation	Treatment	Environment	Effect
Survey or Measurement	Source inventory	Effluent ratio	Plant instrument	Monitoring	Sample test of biology
Formulation	S(x,y,z,t)	Piping or discharge	Process static & dynamic	Environ. model building	Formulation of effect
Prediction	Future prediction			Pollution pattern	Ecological change
Planning & Design	Assessment of production Planning of environmental system	Collection-treatment system	Process design		
Control	Control of environmental system		Process control		

Fig. 3 Constitution of the Sub-projects in Terms of Three Basic Axes.

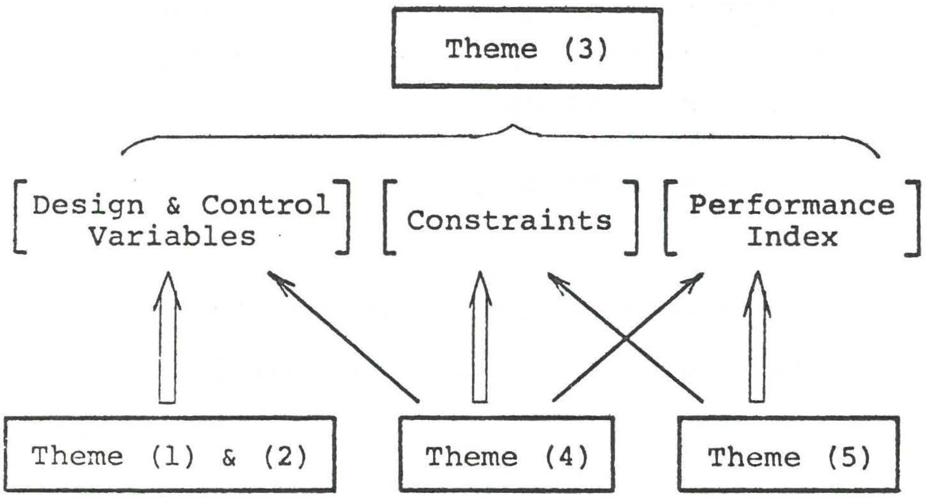


Fig. 4 Inter-relationships of the Major Theme (3) with the Others.

APPENDIX XIII

Global Monitoring:
As A System for Observing the State of the Biosphere and Changes in Its Parameters, and for Estimating Environmental Quality

K.V. Ananichev

When we analyze the interaction of man with the environment we are faced with three main problems which require immediate solution:

- first, estimation of the changes in the Earth's climate and of the geophysical elements of the Earth's surface, as a result of man's activity;
- second, estimation of the degree of chemical pollution of the environment and the geochemical influence of man's activity;
- third, following from the above, estimation of the results of changes in biological productivity of ecosystems and disturbance of their stability under the influence of man produced physical and chemical changes to the environment.

In order to restore the disturbed processes and structural elements of the biosphere and to provide for further rational action between man and the environment, it is necessary, as a first step, to construct system models which show the flow and transformation of material and energy in the biosphere. At present we only have a qualitative concept:

- What comes from where, how, in what quantity and into what is it transformed?
- How great is the area and what is the nature of the anthropogenic deformation of the ecosystem?
- What is the rate of absorption and neutralisation by the environment of various chemical elements?
- In what final form is the damage to the ecosystems expressed in different geographical and physical areas of the Earth?
- And finally, what should be the single system for the general estimation of multilevel interaction between man's activity and different environmental factors?

In order to answer all these questions it would seem reasonable to use monitoring as a system for observing the state of the biosphere and changes in its parameters, and for estimating the quality of the environment. The creators of this system face the problem of finding objective parameters for the evaluation of the biosphere and its different elements, which could be understood like particular cases of more general ecological laws. As a basis for identifying the levels of development of living systems on Earth, ecosystems (biogeosenoses) could be used, since, on this level, the interdependent relationship of living organisms with non-biological environmental factors occurs in full scale.

A monitoring system should begin with a methodological investigation of the following categories:

- What are the concrete reasons for carrying out observations;
- Which processes and ecosystem structures could be the main objects of observation and analysis;
- Which are the factors on which to base analysis in order to obtain satisfactory parameters;
- What should be the principle for distinguishing the points or processes of observation;
- Which methods could provide the solution for the problems which arise;
- What should the nature of basic information be in order to obtain satifactory answers to the questions;
- What strategy should be adopted for working out the general models of ecosystems?

In general, we could answer these questions as follows:

Taking the complex analysis of physical, chemical and biological processes in ecosystems as a basis, the main variables of the most critical environmental problems should be indicated. The solution of the problem is reduced to the question of how to decrease the number of parameters which define the behaviour of the natural ecosystems or ecosystems changed by man, to a reasonable value.

Since, in the first stage of research it is difficult to present the full scope of monitoring problems by a unique model, it is possible, temporarily, and in a certain sense artificially, to separate the points for preliminary and independent analysis. At the beginning, the monitoring system could be considered as a number of subsystems for the estimation of basic parameters by comparison with natural and anthropogenic processes in the biosphere and its elements, i.e. ecosystems.

In this case, the subsystems of physical and chemical monitoring could have as a goal the selection of such physical and chemical parameters, which more than others (typical for these systems) define the conditions of life. However, that does not exclude to any degree the necessity of taking into account biophysical and biochemical processes in the biosphere. At the same time, these systems should be considered as independent, and capable of solving only their own problems.

In general, a monitoring system could be introduced as follows:

I. A subsystem of physical monitoring should consider different actions of man on geophysical structures and processes in the biosphere.

I.I. Analysis of natural climatic rhythms in the biosphere during a period of human activity could be used as basic material. The results of the study of this process through the analysis of deposits in lakes and oceans, and by dendrochronological and other methods could be employed here.

I.2. Large-scale anthropogenic changes of landscape zones or ecosystems, which cause or may cause disturbances to climatic constants in ecosystems can be estimated with reference to:

- decreasing of forest areas and changes in their qualitative composition;
- displacement of desert boundaries;
- destruction of soil and soil erosion by water;
- changing of shore-line of fresh water reservoirs and changing of surface and underground hydrologic regimes;
- increase of urban zones and appearance of arid land.

I.3. Possible influence on the climate of atmospheric and oceanic pollution, examined by the analysis of:

- chemical pollution of the atmosphere and in the sea;
- aerosol pollution in the atmosphere.

I.4. Consequences on climate of thermal pollution.

I.5. Changes to electric, magnetic and radiation fields of the Earth.

2. The goal of this subsystem of chemical monitoring is the definition of the degree and consequences of disturbances of the chemical equilibrium in the biosphere through the activity of man.

2.I. Natural geochemical cycles.

2.2. Natural geochemical (biogeochemical) provinces.

2.3. Forced differentiation between chemical substances on the Earth which occur naturally in connection with mineral extraction.

2.4. Chemically harmful substances:

- poisons;
- biogenics;
- chemical compounds not absorbed by the atmosphere;

2.5. Saturation of the biosphere by foreign chemical elements, such as:

- industrial waste;
- chemical poisons;
- chemical fertilizers;
- surface-active substances;
- polymeric materials;
- medical products.

2.6. Dispersion of radioactive elements.

For the analysis of chemical pollution, which is classified as a mobile form of matter, the results of the analysis of deposits in rivers, estuaries and lakes (as accumulators of chemical pollution) could be used.

3. A subsystem of biological monitoring is not only a product of its physical and chemical components, but also leads to the final goal of research, which consists of the simultaneous study of the cause and consequences in the biosphere of different biological phenomena, which are related to each other in time and space.

Biosystems and environmental factors acting on systems are the subject of biological monitoring. The biological consequences of pollution are the most important in the system of observations and not the pollution and distortion of the environment itself. Therefore, not only the factors which are different in the nature and character of their influence are the subject of monitoring, but various biological "responses" are also observed in living systems as deflections from the normal state. Estimation of tendencies which arise in the biosphere is possible only by means of the constant collection of information in connection with different parameters, which characterize the state of the subject. Therefore, the system of registration and processing of parameters made on the basis of monitoring should, first of all, deal with initial effect and biological "responses".

Therefore, when creating a monitoring system, it is first necessary to stress the central principle of formation of the program - it is not sufficient to limit the sphere of monitoring action merely to the statement of the rate of pollutant accumulation. Measurement of biological "response" should be included from the onset when collecting information. Only the simultaneous measurement of all sets of parameters, which characterize the conditions of observation, provide the possibility of finding a relationship between observations of "response" and initial action.

A system of biological monitoring should be able to predict the evolution of events, i.e. it should constantly make some prediction. This cannot be done without experiments. Therefore, the principal means of collecting information in the system of biological monitoring should be by observation and experiment. Observation is the main organizational form of monitoring which registers the state at any one moment in time.

The specific system of observation of parameters which act on the system should be subjected to a single strategy, the essence of which is the necessity to follow the paths of different pollutants through food chains. At the end, some kind of balance should be established for the most important pollutants in terms of "input" and "output" for the different types of biosystems and different levels of organization.

In the first steps of the organization of monitoring the system of action observation should include more common, more widely spread, and better known environmental pollutants.

A concrete program of observation of biological "responses" to the action of anthropogenic factors should also be subjected to a unique strategy and should indicate deflections from the normal to the pathological among biological "responses" which have been observed and which lead to the destruction of ecosystems. In essence, this is a purely medical statement of the question in connection with living systems, namely the question of the "normal" and "pathological" - and it is the most important, most complex and most urgent question involved in the formulation of the concepts of biological monitoring. It should be taken into account, that complex biosystems whose behaviour depends on a large number of physically different factors, should be treated like a complex system with integral properties, i.e. by special methods, worked out previously for the systems with a "bad" structure.

However, monitoring should not be built up mainly or only in order to acquire information through observation (in the form of description of the results) or analysis of measured variables. Monitoring certainly should have a program, the methodological basis of which is active experimentation. The latter has the goal of studying possible situations, which can be predicted on the basis of the tendencies which have been observed in a changing environment.

For active experimentation enables prediction through monitoring and the connecting of "action-response" within the bounds of a planned experiment.

Recent success in the planning of experiments provides the possibility of studying several sets of actions of many independent variables in natural systems simultaneously and of constructing simple descriptive models.

The latter includes quantitative estimation of the interaction of variables which have a simple biological interpretation. The results of the direct collection of information defines the tendencies towards environmental changes, and provides the possibility for experiments which may be the basis for forecasting the biological consequences of changes in the conditions of existence and behaviour of living matter.

Therefore, the investigation of the movement of pollutants along the food chains, combined with active experimentation, could form the basis for biological monitoring by means of the creation of a unique system of global monitoring, which checks the consequences of changes caused by the activity of man on land, in water and in the atmosphere.

The immediate goal of scientists will probably be the creation of a methodological basis for monitoring and of the particular related models.

APPENDIX XIV

Proposal for Studying An Environmental "Zoo"

M. Fiering

1. Some theorems of ecology:

    a. Man reduces the number of species in the world. This is NOT necessarily BAD.

    b. But reduction implies a loss of stability and most would agree this is bad.

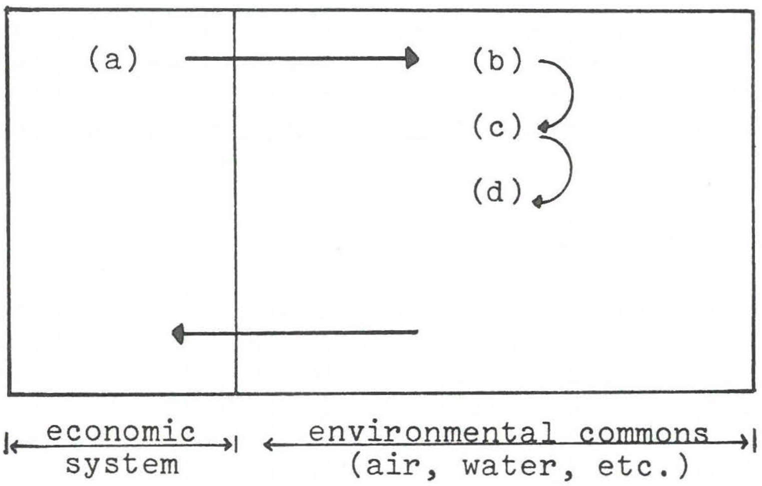
    c. The food web is NOT the same as a network because information in a network still comprises one message if it is redundant. Not true for natural systems.

    d. Energy (or food) passes through a network in an active, not passive, mode. It is grabbed or pushed or eaten, and does not flow of its own accord. Passivity implies stability, but it is not real. Economics is active.

    e. Aquatic and terrestrial models are necessary because these two systems are very different. They may be the only systems. Among the differences are the time constants for these systems, ranging from centuries (for forests) to hours (for small, dependent animals). These differences form the basis of my proposal.

    f. Food sources for one organism are typically negatively correlated with those for another; in sum, the correlation is nearly zero but this is because they cancel correlations, not because each is zero.

2.



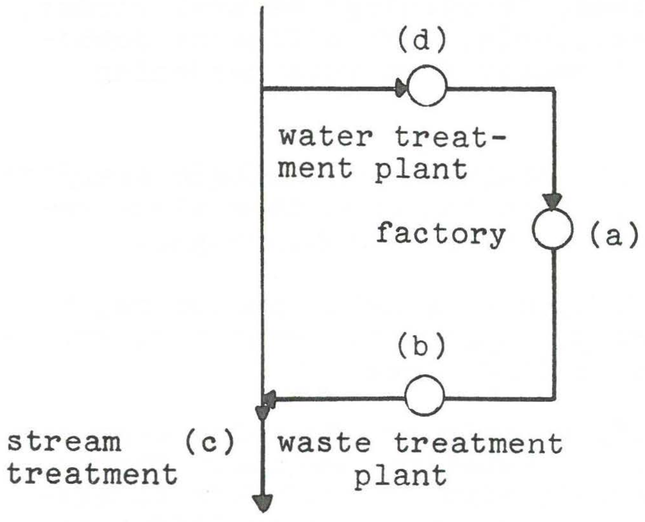
Pollution control can be effected by:

a) economic controls (e.g., low sulfur fuels, standards for adaption and reuse, etc.),

b) treating wastes to make them innocuous (traditional role of sanitary engineering),

c) treating the environment itself so as to accommodate the wastes (future role of sanitary engineering),

d) dealing with pollution (gas masks, water treatment plants, earplugs, cleaning out shellfish, etc.).



We need (e)--the "Zoo--and (f)--capacity for instrumentation and monitoring.

3. An ecologist is concerned with nature's way of doing it, and there is little reason to suspect that this is the best way for man to do it. It is unlikely that our solutions to ecological problems will follow some natural methods, mainly

because we can compress time. This results in an enormous competitive advantage for man, and history shows that whenever it has happened in the past, it has led to massive and complete replacement of fauna or flora by the new type.

4. The Concept of a Zoo

Two major features of ecosystems are (i) environmental pollution due to a significant random accidents which disturb homeostasis, and (ii) the slow rate of recovery from such accidents. We should consider a "zoo" from which it would be feasible to re-seed damaged ecosystems with organisms of appropriate types, in numbers sufficient to trigger rapid recovery of homeostasis (or "ecolibrium"); the zoo would function as an ecological flywheel. We consider below a water resource system.

To maintain such a zoo might cost less than preventing pollution (type a) or reducing it before (type d) or after (type b) the water is used. It is almost surely cheaper than stream treatment (type c). A small injection of organisms might suffice to trigger natural recovery of damaged species, and one should be able to estimate the probability with which episodes of environmental insult occur.

Traditional engineering calls for removal of pollutants from a watercourse; I propose here to stabilize ailing ecologic balances by adding organisms, "hardening" natural riches, and perhaps noting that ecolibria, with different combinations of organisms, will result from this hardening.

5. a) We would have to invent measures of ecologic stability, dispersion, recovery, etc. Much has been done along selected lines, but there are no major breakthroughs.

b) We would have to deal with stochastic processes, biometry, standards, monitoring, economics, chemistry, etc.... The problem cuts across many IIASA areas.

c) The problem of specifying when to add which organisms is an exquisite problem in mathematics; we could devote some time to noting the sensitivity of solutions to different objectives--if indeed there are widely different solutions at all.

d) Institutional issues are a major factor, and I feel that concentration on a small ecoshed, say a lake, would be essential. The primary motion in a lake is vertical, and we know much more about these dynamics than about those in a stream, where the primary motion is horizontal.

6. I carry no major brief for this problem, but suggest it to identify the scale and scope of a manageable research effort. The Alpine Lake Problem is another excellent example.

APPENDIX XV

Development of Ecological Modules

C.S. Holling

There is a pressing need for validated sub-models of key ecological processes (e.g., predation, competition, reproduction, etc.) which are general, precise, and realistic. One of our aims is to develop a library of modules which can be used within any model involving ecological relationships. The aim is to develop equations which, with the minimum number of parameters, contain the variety of behaviors which occur in nature. The approach used to develop these process sub-models involves four stages, each of which is demonstrated by specific examples involving predation and competition.

A. Systems Conceptualization and Identification

(1) The process is decomposed in a series of steps into its constituent components. The components are formally defined as those monotonic relations whose differentials are also monotonic, i.e., simple fragments in which the function consistently rises or falls in a linear, convex, or concave manner. The advantage of this definition is that each relationship is then so simple it is possible to erect alternate hypotheses of causation and design the critical experiments necessary to test the hypotheses.

(2) The components are then identified as basic or subsidiary ones. The former are universal components which underlie all examples of the process, and typically concern fundamental attributes of space and time. The latter are behavioral or physiological components which can be present in some situations and absent in others (e.g., learning). It is these subsidiary components which generate the great variety of forms found in ecological processes. As an example, the predation process has nine subsidiary components which can be present or absent, so that potentially there can be 2^9 or 512 structurally different variants of this response. The great advantage of this technique of decomposition and organization of components is that this high variety can be traced to the operation of a manageable number of components since the variety increases geometrically as the components increase arithmetically.

B. Experimental Analysis and Model Development

The above conceptual framework defines the set of relationships that must be specified for the whole process. Where few data are available, experimental analysis is necessary and the framework provides the organization needed to develop a sequence of experimental steps from which the model evolves. The first step is to devise or discover a situation which is reduced to a set of the basic components and no others. Because it is so reduced, it is simple enough to unravel, experimentally, the actions of and interactions between the small number of components. When adequate hypotheses have withstood experimental testing, they are each expressed as a fragmental equation of a specific action or interaction. These can then be combined into a basic equation representing the combined action of the basic components. This provides the base to proceed to the next step where one additional subsidiary component is added. Again, a situation is devised which is more complex only by the addition of that component and is sufficently amenable to minimize the practical problems of experimental analysis. In this manner, therefore, more and more of the process is analyzed and incorporated within a deterministic simulation model which contains the detailed causal relations.

C. Process (Systems) Analysis

The conceptual framework can be used to deduce the qualitative types of response that are possible. Many of the components, although different in causation, have very similar effects. Thus, although the nine subsidiary components of predation generate 512 structurally different cases, these collapse into eight qualitative types of response, each with a unique form of behavior. Each represents a biologically limiting condition defined by the absence of specific subsidiary components and each has subsequently been shown to exist in nature. At the same time, the full simulation model can be used to generate these same cases either explicitly or as the consequence of a sensitivity analysis. As this is done, it becomes possible to define precisely the biological and physical conditions which define each response type.

D. Development of an Analytically Tractable Module

The simulation model's main value is as a base for deduction and experimentation. Because of their complexity and large number of parameters, they generally are not practical modules to use in the analysis of a specific resource or environmental problem. In such cases it is essential to have simple, analytically tractable modules which are reduced to the minimum number of parameters and yet still generate each of the qualitatively distinct types of response. In the predation example, we were able to design such a module which collapses the 50+ parameters of the simulation model into a tractable five parameter variant. It generates each of the eight qualitative types and faithfully describes all the real life examples of predation, competition by predators, and grazing in the literature. It represents a very general and tested resource acquisition module.

E. Testing the Module

In the final stage the descriptive power of the module is tested in two ways--first against all the cases generated by the full simulation model and second against data in the literature relating to the response.

SECTION FOUR

Participant's Commentary

Conference participants were asked to submit written commentary on various aspects of the Conference. Material received prior to press time is synthesized in this Section. Comments have been quote verbatim where possible but without attribution, as agreed at the Conference.

APPENDIX XVI

Request for Comments and Recommendations

(This document was distributed to participants at the beginning of the Conference)

We are very anxious to get as much advice and guidance as possible from Conference participants. In order to accomplish this in the short time available, we are asking you to submit informal written commentary on Conference issues as they develop. To facilitate the organization of this material, we ask that you present your comments under the following headings:

I. Technical Issues of Ecosystem Analysis
(to be collected at close of morning session on Wednesday; see Agenda.)

Topics include experimental, analytical, mathematical techniques of analysis; hardware and software issues, etc.

II. Development and Application of Ecological Models
(to be collected after afternoon coffee break on Wednesday; see Agenda.)

Topics ranging from project management, through documentation and delivery of information, role of policy persons, etc.

III. Conceptual Issues in Ecosystem Analysis
(to be collected after morning coffee break on Thursday; see Agenda.)

Topics of systems behavior, functional roles, dimensionality, etc.

IV. Specific Project Proposals
(to be collected at close of afternoon Group Discussion, Thursday; see Agenda.)

Here we are concerned both with the identification of priorities for research on ecological systems in general, and with comments on the specific role IIASA might profitably play.

V. Suggestions for Cooperating Institutions
(these may be turned in to the rapporteur at any time during the Conference, or mailed to Dr. C.S. Holling at the address below.)

Please provide the names of persons and institutions which might be interested in working with IIASA in the area of Ecological Systems.

VI. Suggestions of Additional Background Papers

(these may be turned in to the rapporteur at any time during the Conference, or mailed to Dr. C.S. Holling at the address below)

We wish to expand the very preliminary list included in the Conference materials to create a concise but comprehensive background bibliography. Specific references and copies of unpublished manuscripts would be appreciated.

Although we have asked you to submit these informal comments during the Conference, we will be very happy to receive any additional thoughts after the Conference closes. These may be addressed to Dr. C.S. Holling, Ecological Systems Project; International Institute for Applied Systems Analysis; Schloss Laxenburg; A 2361 Laxenburg; Austria. Material received before the end of September can be incorporated in the official Conference Proceedings.

APPENDIX XVII

Suggestions on the Rationale for Project Selection

"I am disappointed that a group of specialists in systems analysis should have reverted to a form of discussion about future projects for IIASA that is no different to the discussions in which I have already taken part in IBP, MAB, SCOPE, FAO, etc. Whatever happened to all the techniques of technological forecasting, including Delphi, relevance analysis, etc.? Instead we ended up 'driving by the seat of our pants,' using the well-worn method of the 'group grope.'"

"I welcomed the suggestion that we develop our major orientation, either as a consensus or as an identified polarity iteratively, but we abandoned this idea before it had ever been properly conceived. If we can't use our own tools to define our aims, why should anyone else use them?"

"A major problem is how to select the proper level (or range) of objectives of the research, for the word ecosystem is used to represent very broad meanings ranging from ocean systems to microscopic societies of insects. Additionally, time scales may also range from the very long time constants of geological evolution to the very short ones of chemical reactions in atmosphere.

We must at first determine the target of our research, that is, the objective and its spatial and time scale. Once it has been selected, all the other factors irrelevant to the target should be neglected so that we may achieve our goals with minimum effort. This will be the problem oriented approach mentioned by Dr. Ananichev. In order to select the appropriate approach, there have been established some techniques, such as Delphi method, brain storming of concerned specialists or the qualification method (developed by Dr. C. Hayashi in Japan and closely related to factor analysis). At any rate, at the beginning of the research, it is necessary to define 'Ecosystem Analysis.' In our research in Japan, for instance, we define that 'Ecology and Industry' represents the interrelation and effects among human activities (especially that of economics), human consciousness and resulting behavior, human and social environment and surrounding natural environments.

It is important that we should not expand the meaning of the word unnecessarily if we want to get some results from the study under the name 'Ecosystem Analysis.'"

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"Brian Mar's third point, about the need for adequate documentation of the systems analysis needs special emphasis and IIASA might well justify its existence by concentrating on developing case studies of the presentation of results and decisions, using ongoing studies. Such an approach would enable a relatively small group to use its talents to the full, without too great a risk of over-commitment. It would also provide a reasonably clear strategy for the 'cycling' of research workers between existing institutes and IIASA."

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"I remain concerned about the need for an adequate data base for any project that IIASA undertakes, and I am not convinced that the Institute can develop the necessary authority and integration of disciplines by using other institutes as the data collection agencies. For one thing, the research workers at these institutes may be reluctant to pass their data to IIASA in a sufficiently raw state for the project team to be able to assess the quality and reliability of the information. Obtaining data from higher level sources (e.g., WHO, WMO, etc.) is even worse, as many of us have found to our cost. Such data have inevitably been 'harmonized,' 'standardized,' and otherwise rendered incapable of objective analysis.

Unless IIASA can choose a project, or projects, for which it can establish its own data base, therefore, I feel it will be reduced to semi-impotence, or condemned to work in the limbo of system models which have no contact with the real ecological world. This is a minority view, but one that I sincerely hold to."

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"While recognizing IIASA's wish to be involved in as many areas of application of systems analysis as possible, I doubt the wisdom of undertaking an ecological project which is separate from the energy project, the water resource project, etc. With the scale of resources available to IIASA, and the constraints imposed by the relatively short term any one worker will spend

> at the Institute, I would have preferred concentration on a major project which included energy, water resources, ecology, human biology, etc. Such a project would really demonstrate the principles so clearly laid down in the 'red book,' and would establish the Institute as an authority on the application of systems analysis. I fear that division of the resources of the Institute to a set of sub-projects will diminish the effectiveness of the Institute."
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>
> "Most groups around today are trying to develop their own ASA teams, so duplication of efforts may be a serious problem. I still think that IIASA could play a really valuable educational role, especially in Europe; this would imply a willingness to step aside quickly when any institution or project gets its own ASA efforts moving. If IIASA leaps into ecological-environmental projects on a consulting or advisory basis, it is almost sure to fail; we have enough object lessons from IBP projects and the like to know that the people who staff most ecological projects must be led very gently into the modelling game."
>
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>
> "It doesn't seem to me that the role of IIASA in the development and application of ecological models can be discussed in isolation of the proposals for the other projects. Could we have more information about the output from the other meetings?"
>
> (Ed. note: Summaries of other Planning Conferences are included in these Proceedings as Appendices XXI through XXVI.)

Finally, one formal comment was received bearing on long term project management within IIASA:

> "My experience advocates in favour of strong professional Project Management action in an institution such as IIASA.
>
> For instance, we have seen the effectiveness of creating ad hoc program boards, formed by individual experts of NMOs, to agree on projects' general lines under the guidance and forum provided by similar institutions. Once the project has been outlined, the institution then provides the mentioned project management on the basis of a clear cut planning (for instance PERT), which of course is subject to iterative review. In case of IIASA, this strong project planning and control would, by the way, make easier the handing over from one project leader to the next one."
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APPENDIX XVIII

Research Priorities and Specific Project Proposals*

A preliminary list of issues for consideration by the Conference was assembled from suggestions of the invited speakers. The revised version is presented below, incorporating participants' suggestions and drawing heavily on a list of "Questions about model use and development," composed by Dr. Dennis Meadows and published in Proc. Nat. Sci. USA.69:3831; 1972.

Conceptual Difficulties in Ecosystem Analysis

- Spatial heterogeneity is clearly important in determining the nature of ecosystem behavior, yet our present ability to treat spatial elements in analytical or simulation models remains extremely limited.
- The various components of ecosystems operate at vastly different rates (e.g., turnover rates), from a few minutes for bacteria to years for higher organisms. How are we to cope with such differences in scale?
- The simplest, and most prevalent approaches in ecosystem analysis are equilibrium or steady-state oriented, yet the equilibrium ecosystem is something which does not, in fact, exist in the real world. How can we generate concepts and models which allow us to anticipate the behavior of disturbed systems?
- High dimensionality becomes a serious difficulty in ecosystem analysis when we designate each species and age class as a separate state variable. Is there a way to work not with species but with larger groupings of functional roles, defining these roles in terms (for instance) of size, trophic habits, and microhabitat?

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*See also the formal submissions presented as Appendices IX - XV.

- Most of our present understanding of ecosystem behavior consists in implicitly tactical conceptualization and models. Is there a place for a strategic or optimization perspective?
- We commonly use energy (or equivalent) units as a basis for our models, yet this may not be the most appropriate approach. Should we be trying to quantify responses in other ways?

Problems of Model Application

Use

- What are the different categories of clients for models and what are their specific information needs? Is there a typology one could use to decide which kind of models a specific decision maker might find most useful?
- What rules can be used to manage a large team of scientists in the effective construction of a model that requires inputs from several different disciplines?
- How can the information in ecological and environmental models be used for policy analysis? How can the decision maker identify the best of several alternative models?
- Existing models tend to be so complex and poorly documented that other groups cannot use them. What can be done to improve the prospects of transferring models from one group to another?

Techniques and Design

- What formal procedures can be used which employ sensitivity analyses and information on the statistical properties of model coefficients to provide an objective measure of confidence in model results?
- What is the most efficient way to identify that part of the model which is most in need of improvement?

- How can hierarchical techniques be used to develop a set of models which deal with related aspects of the same system?
- What protocol seems reasonable in choosing the degree of precision required for a model of specified predictive power?
- When models are developed by groups of experts, what procedures seem to be the most effective in interfacing the talents of subject matter specialists, systems people,and policy people?
- How can we improve the process through which analyses of the model lead to a refined research strategy and additional measurements on the real world?
- Should we consider working in other mathematical forms beyond the present space-time use of differential or difference equations?

Several other broad classes of issues relevant to IIASA priorities were posed in post-Conference submissions:

> "To what degree are ecological principles applicable to urban settlements? Can such derivations be applied to improved urban design?"

> "What is the cost of maintaining <u>unstable</u> systems? Much of agricultural and some other intensively managed ecosystems <u>input</u> fossil fuel energy in order to gain an increment of biological energy as output. There may be other parameters to measure the cost of husbandry. Such concepts could be readily translated into economic application."

> "The concept of capacity for intensity of particular uses or mixtures of multiple uses by man needs operational expression. Thus, ecological carrying capacity has integrated successional stage, diversity, persistence, and resilience as applied to management of some grazing systems. Both theoretical development and applicable models are needed for many other ecosystems and perturbations."

Specific project recommendations were made in a number of areas. Many participants argued for a methodological emphasis in IIASA's ecological projects:

> "Having listened with interest to the arguments and counter-arguments developed during the last three days, I come firmly to the conclusion that IIASA should develop its thrust as a high quality research institute. For this reason, I believe that the proposals made by East Germany and the Soviet group are too complex and too diffuse to provide the necessary leverage. Similarly, the world-model orientation seems to me to be too remote from any scientific methodology to do the Institute any good in establishing its reputation. The more specific ecological projects, e.g., Alpine lakes, ecosystem studies, on the other hand are too limited in scope to establish the Institute as anything more than a competitor with more traditional ecological institutes and programs. There is also a grave danger that the Institute will take on a program which overlaps rather than complements the programs of international agencies.
>
> In contrast, there are some areas of methodological research in which IIASA could have a rapid and influential impact by developing explicit techniques of applied systems analysis which can be seen to have wide applicability to ecological research elsewhere. I would suggest the following:
>
> (1) Development of a module library for ecological processes as a possible basis for large scale modelling;
>
> (2) Development of techniques to demonstrate and resolve conflicts between national and sub-national policies for resource management;
>
> (3) Analysis of the prior probabilities which can be ascribed to competing models -- the comparison of alternate lies;
>
> (4) Review of systems analysis techniques appropriate to studies of ecological problems at various levels -- ecosphere, ecosystem, trophic, etc.;
>
> (5) Development of the appropriate sampling and systems analysis techniques which are appropriate to the monitoring of

change in the environment and especially of ecological change;

(6) Development of techniques appropriate to the modelling of ecosystems with respect to stability, instability, and the principles of the analysis of the controllability of such systems;

(7) Mathematical formulation of risk categories in the construction of indices of well being, for application to the perception of environmental quality;

(8) Development of methodology for the construction of regional resource development projects and models."

Little explicit distinction was made between methodologies of systems analysis and synthesis during or after the Conference.

> "No distinction has been made between ecosystem analysis and ecosystem synthesis, but much of the discussion has really been about ecosystem synthesis. Is there any intention that IIASA will undertake the analysis of ecosystems into their component cycles, etc.? The two strategies seem to me to require different mixes of disciplines."

This bias was reflected in the commentary as well, where the preponderance of submissions dealt with various questions of system synthesis. For instance,

Spatial heterogeneity

> "There is a tendency in ecosystem modelling to use the most obvious approach to spatial heterogeneity; i.e., some explicit grid or cell system. More attention should be paid to finding implicit representations of the effects of spatial heterogeneity, such as the analytical approach used so successfully by Dr. Steele."

> "What is the appropriate way in which to treat heterogeneity in simulation models where the behavior of a group of components can be described

in terms of a common set of functions, and the heterogeneity can be expressed by a joint statistical distribution of the parameter values?"

"For purposes of operational management of ecosystems how can spatial and temporal heterogeneity be sufficiently considered? What constitutes sufficiency re any applied question, other than statistical variance?"

Hierarchical organization

"Dr. Goodall emphasizes the need to find better ways of analyzing and recognizing patterns of hierarchic organization in ecosystems. We do not know for sure if most ecosystems are hierarchically organized into functional units broader than the niche. Methodological research on detection of hierarchic patterns in complex systems would be most useful."

"I would support an attempt to construct partial models to be used like elementary building blocks (or a "module library" as Dr. Holling had called it) to be later assembled for simulation of specific cases. Accepting entirely the critics and limitations (optimization of such a system is not of necessity optimization of the system), I wish to submit that the procedure can serve nevertheless some useful purposes. For instance, it is easier to test, or calibrate a sub-model than a complex global model. This can be done both by applying it to retrospective cases with sufficient data base, and/or by experimentally reproducing the simplified sub-system."

And parameter estimation

"I think one of the most important points of methodology of system theory is identification. I definitely believe that identification methods could have a serious impact on the environmental area. In particular, parameter estimation algorithms will be more and more useful in the field of modelling of ecosystems. Therefore, my opinion is that IIASA should try to emphasize research in this area."

Other suggestions bore more directly on questions of ecosystem analysis.

> "Quantitative analysis designed to elucidate mechanisms of evolution and dynamic change in specific ecological systems will be most difficult. In the real world the systems which interest us are intricately entangled with one another, and we cannot generally separate these complex interrelationships by observation. This is true because we can, in general, only observe present equilibrium or steady-state conditions which do not help us to clarify dynamic causalities or even static interrelationships. Really useful data can be obtained only when we are allowed -- and able -- to change the state of the system and observe its response, and this occurs very rarely.
>
> It is this very issue which makes the 'identification' problem in ecology so much different from that in artificial systems such as chemical plants or other industrial processes. Yet, in order to protect ecosystems from destruction by human society, it is indispensable that we learn to understand the effects on ecological systems caused by external disturbances.
>
> Given this situation, one way to obtain the necessary knowledge of underlying ecosystem mechanism is to conduct long-range observations of the real ecosystems. This should be done in isolated situations such as ocean islands or lakes in undeveloped areas, where the components of the system are relatively few and comparatively sensitive to external disturbances. It is easier to determine the mechanism of such simple systems, and dynamic causalities may be determined from the response to induced perturbations.
>
> Alternative approaches to the identification of system response involve the observation of isolated industrial operations. Some work of this sort is now underway in a small bay within the Inland Sea of Japan, where only one factory stands and the effects of pollutants on the environment can therefore be unambiguously analyzed.
>
> Such analyses, however, require a large commitment of time, money, and manpower, and only a very few actual cases can be studied in great detail. For this reason, I believe that Prof. Holling's idea of a 'module library' would be a most reasonable

> way to obtain the understanding we desire. Real technical and conceptual difficulties (involving considerations of scale, resolution, and objectives) would arise in specifying the proper subject matter of the individual modules and in developing techniques through which they could be effectively integrated to address specific problems."

> "During the Conference, many participants spoke about stability analysis of ecosystems as a key point. Going carefully through the reports and the statements, one can easily understand that reference is made to the classical kind of stability. Concepts like resilience are nothing other than classical investigations of 'stability in the large.' On the other hand, when examples are dealt with, different types of stability concepts are involved. In particular, perturbations on the structure of the systems due to man activities are often considered. This implies that the stability theory needed to take care of these cases is not the classical one (where the perturbation is on the state variables) but a structural perturbation kind of stability. Therefore, as a theoretical interest in the theory of ecosystems, I suggest that IIASA could develop some study in the area of structural stability."

Proposals utilizing available methodology to address specific applied problems were also put forward:

> "I wonder whether it could be in line with the general scope of the Institute that the Institute itself starts developing certain models which are general enough to serve to the member states -- collectively or individually -- for the analysis of some of their problem areas. In suggesting this issue I am thinking mostly to the problems raised by pollution from various origins, in air, soil and waters. One could identify several areas of large enough interest to be addressed by IIASA to the benefit of its members. For example:
>
> - a largely general model simulating a hypothetical geographical surface which contains a cluster of the most significant elements of the natural environment (forest, lake, river, sea shore, . . .) and of man-produced environment-disturbing factors, such

as settlements, industry, agriculture, transportation;

- an attempt to construct partial models to be used like elementary building blocks to be composed for simulation of specific cases;
- a general model for a semi-internal sea to be applied by concerned groups of member states to analyze and plan the situations in the Black Sea, the Mediterranean, the North Sea, and the Baltic Sea. This would be a case of large ecosystems with external disturbances of liquid, solid, and air pollution from coasts and ships, microclimatic effects, fish harvest, etc.
- the alpine system, mainly its hydrographic sub-system with implication of waters use and re-use for energy generation, irrigation, industry, water-bearing strata, etc.

A list of important topics to be addressed by the latter project would include the following:

1. Definition of quality of Lakes, Rivers, Glaciers, etc.
2. Role of Vegetation, Wildlife and Microorganisms
3. Consequences of Technological Development
4. Consequences of Agriculture
5. Consequences of Urbanization
6. Definition of a Legislation.

Some advantages of this project are that it would

- be focused on a practical case;
- be relevant to many of the members of IIASA;
- be of universal interest;
- be urgent; and
- offer strong interactions with other IIASA projects."

Other possible areas for work by IIASA were also proposed:

> "Recent breakthroughs in climatic models now permit more refined predictions of crop yields in large continental areas. Considerable importance accrues to industrial nations if simultaneous crop failures occur on several continents. Economic systems are then stressed to obtain some measure of relocation of food surplus. Increasingly there are few surpluses. World wheat reserves fell to 30 days this year. Climatologist Dr. Reid Bryson of the University of Wisconsin suggests that the pattern of monsoon rains has shifted significantly for perhaps several decades. The current Saharan drought is a manifestation which may persist and occur elsewhere over the next four decades."

> "Suggestions for topics in human ecology:
>
> (a) Emergence of problems resulting from over-programming of people; investigations on the scheduling of activities in an urban environment and, more widely, in contemporary society; including treatment of chronometric time, rhythms, and natural cycles.
>
> (b) Organized and spontaneous phenomena; the phenomena of adjustment (spontaneous) and regulation (legal and administrative) in the social ecosystem; development of strategies for the programming of social activities.
>
> (c) Risk and safety factors in the contemporary social system; events connected with hazard in such a system, problems posed by accidents and natural disasters; the bio-anthropological extension of the notion of social security.
>
> (d) Evaluation of the ecosystemic regulation of human population growth.
>
> (e) The economic concept of waste.
>
> (f) The concepts of territory and aggression; a critical examination of the transference of concepts from animal ethology to the scientific study of man.
>
> (g) Studies of traumatic modifications caused by man in the relationship between natural and human ecology."

"An appropriate role for IIASA in systems analysis training needs to evolve complementary to its prime purpose and commitment to advanced research."

APPENDIX XIX

Suggestions of Cooperating Projects, Institutions, and Individuals

In written commentary received after the Conference, participants suggested that IIASA might seek to develop contacts with the individuals, institutions, and projects given below. This constitutes a very preliminary list, reflecting only those suggestions advanced during and immediately following the Conference. It will be expanded through consultation with the various National Member Councils and experts in the field.

Italy

	Institution	Name	Topics of Interest
1.	Joint Research Center Euratom - Ispra (Varese)	Dr. G. Di Cola	Modelling of Ecosystems
2.	Istituto Botanico Università di Trieste Trieste	Prof. Pignatti	Modelling of Ecosystems
3.	IRSA Via Reno 1 Roma	Prof. Passino	Water Pollution
4.	Ist. Ital. di Idrobiologia Pallanza Verbania (Novara)	Prof. Tonolli	Water Pollution Modelling of Ecosystems
5.	Laboratorio per l'Inquinam. Atmosferico C.N.R. - Roma	Prof. Cantutti	Air Pollution
6.	Istituto Botanico Università di Roma Roma	Prof. Giacomini	Modelling of Ecosystems
7.	I.F.A. - C.N.R. Sezione Microfisica Bologna	Prof. Vittori	Air Pollution
8.	Tecneco Fano (Pesaro)	Dr. Fossa Margutti	Air and Water Pollution

Italy (con't.)

9.	Idrotecneco Fano (Pesaro)	Dr. Baulino	Water Pollution
10.	Montedison Uff. Protez. Ambientale e Sicurezza Via Turati 7 Milano	Dr. Cividalli	Water and Solid Pollution
11.	Montedison Div. Prodotti Industriali p. za Repubblica 14-16 Milano	Dr. De Manzini	Water and Solid Pollution
12.	ENEL Centro di Ricerca Technica e Nucleare Bast. di Porta Volta Milano	Dr. Borgese	Air and Water Pollution
13.	ENEL Centro di Ricerca Idraulica e Strumentale Via Gattamelata 34 Milano	Prof. Fanelli	Flood Control
14.	Ist. Di Elettronica Via Gradenigo 6/A Università di Padova Padova	Prof. Ciscato	Water Pollution
15.	Ist. di Elettrot. e Elettr. Via A. Valerio 10 Università di Trieste Trieste	Prof. Milo	Land Use

Italy (con't.)

16.	Tecneco Via S. d'Amico 40 Roma	Dr. Scaiola	Land Use
17.	Centro Studi Cibernetica Ambientale Via Cavour 35 Torino	Prof. Mosso	Modelling of Ecosystems
18.	Centro Teoria dei Sistemi-Politecnico P. za L. da Vinci 32 Milano	Prof. Rinaldi	Air and Water Pollution Modelling of Ecosystems
19.	FIATMARE Torino	Dr. Montalenti	Air and Water Pollution
20.	FIAT Gruppo Ricerca Operativa Torino	Dr. Grilli	Land Use
21.	Università di Torino & Head of Direzione Sistemi ed Informatica FIAT Via Leonardo da Vinci 15 Torino	Prof. Lionello Cantoni	Computer and Systems Scientist
22.	Istituto di Ricerche di Cibernetica Arco Felice Napoli	Prof. Caianiello	Cybernetics, Mathematics, Education, Systems Analysis

Italy (con't.)

23.	Centro Interdisciplinare di Recerche Territoriali (CIRTE) c/o Politecnico di Milano Piazza Leonardo da Vinci 32 Milano	Prof. Adriano de Maio	Pollution Problems, Natural Resources Management - energy and water sources
24.	TEMA Via Marconi 29/1 Bologna	Ing. Paolo Verrecchio	A private mathematic and systems analysis company

Japan

Institution	Name	Topics of Interest
Kyoto University Department of Applied Mathematics Kyoto	Dr. Y. Sawargi	He is the leader of an Environmental Pollution Control Project, sponsored by the Ministry of Education. Details of field of research are in the paper by Dr. Naito, Appendix XII.
National Institute of Environmental Pollution Research Office of Environmental Information 3-1-1 Kasumigaseki, Chiyoda-ku Tokyo 100		Analysis and future prediction of ecosystem of Japan and the world. Modelling of environmental system, analysis of effect of pollutant to living matters and some others.
Department of Chemical Engineering & Institute of Systems Synthesis and Optimization Kansas State University Manhattan, Kansas 66502 U.S.A.	Prof. Liang-tseng Fan	Modelling of environmental systems (both river and air sheds). Environmental system design and control.
Japan Ministry of Industry and Commerce Kasumigaseki, Chiyoda-ku Toyko 100	S. Gotoh	Modelling of waste treatment process system.

Japan (con't.)

Department of Environmental Planning College of Art of Osaka Osaka	Harvey Shapiro c/o Prof. Tomoya Masuda Dept. of Architecture Kyoto University Sakyo-ku Kyoto	Regional Planning.

United Kingdom

The Secretary
Natural Environment Research Council
Alhambra House
27-33 Charing Cross Road
London WC2

Sir Kingsley Dunham
Institute of Geological Sciences
Exhibition Road
South Kensington
London SW7

Dr. R.S. Glover
Institute for Marine Environmental
Research
13-14 St. James Terrace
Plymouth

Prof. F.T. Last
Institute of Tree Biology
c/o Dept. of Forestry
University of Edinburgh
King's Buildings
Mayfield Road
Edinburgh
EH9 3JU

The Deputy Director
Institute of Terrestrial Ecology
Merlewood Research Station
Grange-over-Sands
Lancashire

Dr. J.S.G. McCulloch
Institute of Hydrology
Howberry Park
Wallingford
Berkshire

Prof. H. Charnock
Institute of Oceanographic Sciences
Wormley
Godalming
Surrey

Prof. L. Foden
Rothamsted Experimental Station
Harpenden
Hertfordshire

The Professor
Dept. of Forestry and Natural
Resources
University of Edinburgh
King's Buildings
Mayfield Road
Edinburgh
EH9 3JU

The Director
East Malling Research Station
East Malling
Maidstone
Kent

United Kingdom (con't.)

Prof. E.K. Woodford
Grassland Research Institute
Hurley
Near Maidenhead
Berkshire

Prof. D.W. Wright
National Vegetable Research Station
Wellesbourne
Warwick

G.D. Holmes, Esq.
Forestry Commission
Alice Holt Lodge
Wrecclesham
Farnham
Surrey

Prof. J.L. Harley
Commonwealth Forestry Institute
University of Oxford
South Parks Road
Oxford
OX1 3RB

Prof. T.R.E. Southwood
Imperial College of Science and
Technology
Exhibition Road
London SW7

Prof. A.J. Rutter
Imperial College Field Station
Silwood Park
Ascot
Bershire

Prof. M. Williamson
Department of Biology
University of York
Heslington
York
YO1 5DD

United States

Institution	Principal Investigator	Project Title
Michigan State University	H. E. Koenig	Design and Management of Environmental Systems
University of Chicago Argonne National Laboratory	G. Tolley K. Croke	Environmental Pollutants and the Urban Economy
Iowa State University	E. O. Heady	National Environmental Models of Agricultural Policy, Land Use and Water Quality
University of Houston	R. G. Thompson	National Economic Models of Industrial Water Use and Waste Treatment
Oak Ridge National Laboratory	C. W. Cravens, Jr.	Regional Environmental Systems Analysis
The Center for the Environment and Man, Inc.	G. R. Robinson	The Impact of Economic Development and Land Utilization Policies on the Quality of the Environment
Harvard University	C. F. Steinitz	The Interaction between Urbanization and Land Quality and Quantity in Environmental Planning and Design

United States (con't.)

Dartmouth College	D. L. Meadows	Natural Resource Availability and Policy Implications in the U.S.
Colorado State University	D. A. Jameson	Regional Analysis of Grasslands Environmental Systems
University of California, Davis	K. E. F. Watt	Land Use and Energy Flow in a Human Society
University of Washington	J. S. Bethel	Models of the Forest Ecosystem of the Snohomish River Drainage Basin

United States (con't.)

Institution	Name	
Institute for Environmental Studies University of Washington Seattle, Washington 98195	Prof. R. O. Sylvester Director	
The Institute of the Environment Laboratory of Limnology University of Wisconsin Madison, Wisconsin 53706	Arthur D. Hasler	
Southwest Fisheries Center National Marine Fisheries Service P. O. Box 271 LaJolla, California	Dr. Brian J. Rothschild Director	(One of the few fisheries scientists in USA that strongly advocates systems analysis.)
Management and Organization University of Washington Seattle, Washington 98195	Dr. William T. Newell	

Institution	Name	Topics of Interest
	Ireland	
Department of Civil Engineering University College Dublin	Dr. James Dooge	Hydrologist, knowledgeable in statistics and hydrological simulation
	Norway	
Norsk Institutt for Skogsforskning N-1432 As-NLH	Prof. Kristian Bjor	One of key men in the Norwegian portion of air quality control and monitoring scheme. Very interested in systems analysis.
	Prof. Rolf Vic	Norwegian MAB committee member currently on half time to the Miljovern Dept. (i.e. Department of Environment); one of his tasks is to prepare the MAB proposal for the Storting (Parliament)
	Sweden	
Teknikum Box 534 S-75121 Uppsala 1	Laborator Torgny Schütt	Leading the "systems analysis" group for Swedish MAB project in Coniferous Forest

International Groups

Projects of the International Decade of Ocean Exploration:

a) Controlled Ecosystem Pollution Experiment (CEPEX) - described in Appendix VI; involves laboratories in the U.S., Canada, and the U.K.

Scientific Leader	Key Individuals	Key Institutions
Dr. David Menzel Skiddaway Institute of Oceanography Savannah, Georgia U.S.A.	Dr. T. Parsons University of British Columbia	National Science Foundation U.S.A.
	Dr. J.H. Steele Marine Laboratory Aberdeen Scotland	University of British Columbia Canada
		Marine Laboratory Aberdeen Scotland

b) Coastal Upwelling Ecosystem Analysis (CUEA)

Scientific Leader
Dr. R. Dugdale University of Washington Seattle, Washington U.S.A.

APPENDIX XX

Suggestions for Background Papers

This is a preliminary list of papers relating to the keynote addresses and the general subject areas addressed by the Conference. It was assembled from material provided by the invited speakers, and revised to include suggestions from Conference participants. The list forms the core of a background bibliography on the synthesis and analysis of ecological systems, under preparation by the present IIASA Ecology Project.

Papers by Invited Speakers

C.S. Holling

C.S. Holling. In press. Resilience and Stability of Ecological Systems. (Ann. Rev. Ecol. Syst., 4)

C.S. Holling & A.D. Chambers. 1973. Resource Science: Nurture of an Infant. BioSci. 23:13-20.

C.S. Holling. 1972. Ecological Models: A Status Report. In A.K. Biswas (ed.). Int'l Symp. on Modelling Techniques in Water Resources Systems. Proc. Environment Canada, Ottawa.

Henry A. Regier

H.A. Regier. In prep. Some Approaches to the Study of the Response of Fish Communities to Stress. (Draft. Chapter for forthcoming Population Dynamics of Fishes. J.A. Gulland (ed.).)

H.A. Regier. 1972. Community Transformations--Some Lessons From Large Lakes. Pp. 35-40. In Proc. of the 50th Year Anniversary Symposium, Univ. of Washington College of Fisheries.

H.A. Regier & H.F. Henderson. 1973. Towards a Broad Ecological Model of Fish Communities and Fisheries. Trans. Amer. Fish. Soc. 102:56-72.

H.A. Regier & W.L. Hartman. 1973. Lake Erie's Fish Community: 150 Years of Cultural Stress. Science 180:1248-1255.

David W. Goodall

D.W. Goodall. 1973. Problems of Scale and Detail in Ecological Modelling. (To be published in Conference Proceedings.)

D.W. Goodall. In press. Ecosystem Modelling in the Desert Biome. (To be published in Systems Analysis in Ecology, Vol. 3. B.C. Patten (ed).)

D.W. Goodall. 1972. Building and Testing Ecosystem Models. In Mathematical Models in Ecology, J.N.R. Jeffers (ed.).

J.H. Steele

J.H. Steele. 1973. Patchiness in the Sea. (Unpublished MS.)

J.H. Steele. 1971. Factors Controlling Marine Ecosystems. Nobel Symp. 20: 209-221.

Brian Mar

B.W. Mar. 1973. Where Resource and Environmental Simulation Models Are Going Wrong. (To be published in Conference Proceedings.)

B.W. Mar. 1972. Integrated Information Systems for Utilities? MS.

C.J. Walters

C.J. Walters. 1973. An Interdisciplinary Approach to Development of Watershed Simulation Models. (Unpublished MS.)

C.J. Walters and I.E. Efford. Systems Analysis in the Marion Lake IBP Project. Oecologia (Berl.) 11:33-44.

C.J. Walters. 1971. Systems Ecology: the Systems Approach and Mathematical Models in Ecology. In Fundamentals of Ecology. (3rd ed.) E.P. Odum. Saunders.

Additional Papers, by Subject Area

CONCEPTS IN ECOSYSTEM ANALYSIS

N. Gilbert and R.D. Hughes. 1971. A Model of an Aphid Population--Three Adventures. J. Anim. Ecol. 40:525-534.

C.D. Huffaker, K.P. Shea, and S.S. Herman. 1963. Experimental Studies on Predation. Complex Dispersion and Levels of Food in an Acarine Predator-Prey Interaction. Hilgardia 34: 305-330.

Richard C. Lewontin. 1969. The Meaning of Stability. In Diversity and Stability of Ecological Systems. Brookhaven Symposium in Biology 22:13-24.

R.M. May. 1971. Stability in Multi-species Community Models. Math. Biosciences 12:59-79.

R.M. May. 1972. Will a Large Complex System be Stable? Nature 238:413-414.

R.M. May. 1972. Limit Cycles in Predator-Prey Communities. Science 177:900-902.

R.D. Morris. 1963. The Dynamics of Epidemic Spruce Budworm Populations. Mem. Ent. Soc. Can. 31:1-332.

F.E. Smith. 1972. Spatial Heterogeneity, Stability, and Diversity in Ecosystems. In Growth by Intussusception. Z.S. Deevey (ed.). Archon Books, Hamden, Connecticut (USA).

W.E. Ricker. 1954. Stock and Recruitment. J.Fish Res. Bd. Can. 11:559-623.

TECHNICAL PROBLEMS OF ECOSYSTEM ANALYSIS

G.S. Innis. 1973. Future Directions in Ecosystem Modelling. Draft MS presented at USNC-IBP Interagency Coordinating Committee Meeting, 26-27 July 1973.

J.W. Young, W.F. Arnold, J.W. Brewer. 1972. "Parameter Identification and Dynamic Models of Socioeconomic Phenomena." (This paper suggests a different approach to simulation modelling where parameters are identified by a desired trajectory of outputs. This is inverse to the normal approach of selecting parameters to determine a trajectory.

Other papers by Brewer expand on this concept. It is an alternative to the sensitivity study suggested by Tawari; papers published in IEEE Trans. on Systems, Man, and Cybernetics, Vol. SMC-2. No. 4, Sept. 1972 . Paper includes example using Tahoe GUESS model.)

M.E. Vinogradov, V.V. Menshutkin, and E.A. Shushkina. 1972. On Mathematical Simulation of a Pelagic Ecosystem in Tropical Waters of the Ocean. Marine Biology 16:261-268.

J.J. Walsh and R.C. Dugdale. 1971. A Simulation Model of the Nitrogen Flow in the Peruvian Upwelling System. Investigacion Pesquera 35(1): 309-330.

J.N.R. Jeffers (ed.) 1972. Mathematical Models in Ecology. Blackwell Scientific Publications. Oxford.

IEEE Trans. on Systems, Man, and Cybernetics, Vol. SMC-2(4): 460-467.

DEVELOPMENT AND APPLICATION OF ECOSYSTEM MODELS

Richard C. Duncan. 1973. "Techniques and Guidelines for Rapidly Building Models Concerning Simulation of Regional-Environmental Systems: An Application to Land-Use Planning on Orcas Island, Washington." Ph.d. dissertation, University of Washington. (This is a thrust by one of Mar's students to apply the interaction matrix concepts to variables rather than subroutines. It has proven highly effective in the conceptualization of models.)

B.J. Rothschild and J.W. Balsiger. 1971. A Linear Programming Solution to Salmon Management. Fishery Bulletin, Vol. 69, (1):117-140.

B.J. Rothschild. 1973. Questions of Strategy in Fishery Management and Development. In Technical Conference on Fishery Management and Development, Vancouver, Canada, 13-23 February 1973. FAO, FI:FMD/73/S-42.

B.J. Rothschild. 1972. "The Need for Analysis in the Development of United States Fisheries Policy." (An argument for the application of systems analysis to fisheries management.) In B.J. Rothschild (ed.), World Fisheries Policy. Univ. Washington Press, Seattle.

G.J. Paulik. "Fisheries and the Quantitative Revolutions." (A discussion of the role of computers and quantitative analysis for complex systems, including the resolution or precision issue.) In B.J. Rothschild (ed.), World Fisheries Policy. Univ. Washington Press, Seattle.

Journal of Environmental Management (quarterly). Academic Press, London and New York.